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SOIL GROUPS OF UPLAND FORESTS

by D. G. PYATT, B.Sc.

Forestry Commission

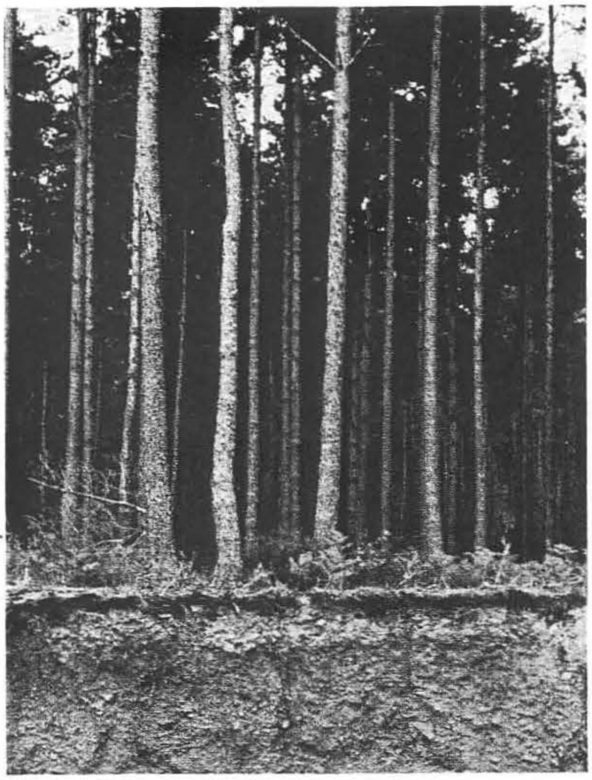

PLATE 1 **PODZOL**

A well-developed podzol in glacio-fluvial gravel, with the traditional crop of Scots pine. This deeply rootable soil should be capable of supporting a higher-yielding species. Speymouth Forest, Morayshire.

PREFACE

This paper is intended as a guide to the recognition and properties of the main groups of soils which occur in upland forests. For present purposes "Upland Britain" is defined as those regions underlain by rocks of Carboniferous and older series, plus the North York Moors which are formed from rocks of Jurassic age. Igneous intrusions within these areas are also included, regardless of their age. The boundaries of upland Britain are shown in Fig. 1, page 5.

Whilst a comprehensive classification of upland forest soils is in preparation and will be published in due course, it has been decided to prepare this paper to enable Forestry Commission staff and other foresters to have access to the basis of the classification which has been developed during the past seven years of forest soil survey. The properties of seven broad groups of soils are described, supplemented by a brief discussion of soil processes and soil-forming factors necessary to the proper understanding of the groups. An attempt has been made to reduce the number of technical terms, and those used are explained in a glossary (p. 45). Terms included in the glossary are indicated by an asterisk when first used in the text.

The colour plates are from transparencies by the author. Examples of soils in Wales have not been included because they are illustrated in another publication, namely Forest Record No. 69, *Guide to Site Types in Forests of North and Mid Wales*, H.M.S.O., 1969, price 8s. 0d. (40p).

ACKNOWLEDGEMENTS

The author is grateful to the many colleagues who gave assistance of various kinds in the preparation of this Record, particularly the soil survey foresters who carried out the fieldwork on the results of which the Record is based. Mr. B. W. Avery of the Soil Survey of England and Wales, Rothamsted, and Dr. W. O. Binns, Soils Section, Forestry Commission Research Division, read the manuscript and gave many valuable comments.

CONTENTS

INTRODUCTION

The soil classification set out here may be described as a special-purpose classification in that it is designed specifically for use in forestry. The greatest emphasis is placed on those soil properties which affect forest yield and which, although they may be modified by cultural operations, are relatively permanent limitations on the use of the soils. Such properties include the natural drainage status, the available depth for rooting, the presence of compact or cemented layers, the texture, the general level of acidity or alkalinity, and the occurrence of peat. Properties which may constitute limiting factors in some situations, but which can usually be comprehensively altered by cultural practices, such as general nutrient levels and the presence of certain competitive weed species, are not used to differentiate the soils, although they are discussed along with the other properties of each soil.

The soil classification is therefore in large measure also a site classification, that is, it forms the basis for the delineation of types of ground for each of which a distinct form of silviculture may be appropriate. Traditional site classifications have mainly been based on bare ground vegetation types (e.g. Anderson 1950) and have been designed essentially for the selection of tree species. Our knowledge of the site requirements of the major species is continually improving, while the number of widely planted species is tending to decrease for financial and marketing reasons. As a result, choice of species is somewhat less of a problem than formerly, while the selection of the appropriate site improvement techniques in order to obtain optimum productivity from the species planted is the main purpose of this classification. A soil based site classification enables detailed specifications to be given for such operations as cultivation, drainage, fertilization, and (when the exposure of the site is also estimated) allows the assessment of windthrow hazard. Although the detailed specifications for individual soil types cannot be included in this paper, sufficient discussion of the forestry properties of each soil group is given to indicate the application of the classification in these terms.

The soil classification cannot be considered to be the complete site classification in that it does not take special account of some potentially limiting factors such as slope gradient and the occurrence of boulders, or climatic factors including wind exposure. While slope gradient and boulders are not used to characterize the soil types of the classification, these features have been used in soil surveys to define mapping units which are in effect subdivisions of soil types, where local circumstances have suggested that this would be worthwhile. Exposure to wind is such an important factor in upland forestry that it is assumed here that a separate assessment of it will usually be required, in order to characterize a site adequately. A method for estimating the exposure of a site relative to that of other locations in the forest is at present being tested; it is known as the "topex" method (Pyatt, Harrison and Ford, 1969, Neustein 1968).

The purpose of the forest soil classification is therefore essentially equivalent to that of a *land capability classification*, in that it allows the assessment of the uses to which the land can be put (choice of species), and indicates the limiting factors present. In the view of the author it has the advantages over a typical land capability classification of greater simplicity and convenience of terminology. The relationships between classes (or types) are also more clearly indicated, whereby the relevant information is conveyed more effectively.

Fig. 1. Ulpand Britain (shaded).

FORMATION

1.1 SOIL PROCESSES

1.1.1 Weathering

Physical weathering plays an important role during the early stages of soil development, particularly in the formation of the soil parent material. Most of the soils in our upland areas are formed in glacial or periglacial deposits, which were produced by physical weathering and transported by ice, meltwater or directly by gravity. These materials range from coarse scree to finely comminuted tills, and thus exhibit varying degrees of physical weathering. In general, however, these drift materials are only slightly chemically weathered at the time of deposition.

During soil formation proper, the parent material undergoes chemical weathering, while the physical processes continue at a slower rate than before. Initially the principal agent of chemical weathering is percolating rainwater charged with carbon dioxide dissolved from the atmosphere. Rock minerals such as felspars, micas, pyroxenes and amphiboles have complex molecules consisting essentially of aluminium silicates with one or more cations (metals) such as potassium, sodium, calcium, magnesium or iron. These are broken down (or hydrolyzed) by acidified water to produce clay minerals, which are also complex silicates, and to release some of the metal ions. These may either form insoluble oxides such as iron oxides or aluminium oxides or be dissolved in the water and removed. Some of the soluble metal ions become attached to the clay particles. Resistant rock minerals such as quartz are little affected and tend to accumulate in the soil as sand- and silt-sized grains. Soluble minerals such as carbonates are dissolved and removed.

1.1.2 Incorporation of organic matter

Plant remains are added to the soil either directly or through animals and disintegrate and decompose more rapidly than the mineral soil. Part of the organic material is oxidized (mineralized) to release nitrogen and other mineral nutrients back to the soil, while part is transformed into humus and mineralizes at a slower rate. Substances released from plant roots and organic acids formed during the decay of plant material greatly intensify the chemical weathering processes affecting the mineral soil fraction.

1.1.3 Leaching

The process of leaching refers to the removal of *readily soluble* components such as the chlorides, sulphates and carbonates of sodium, potassium, calcium and magnesium. The upper soil horizons are continually being depleted of these components, leading to the development of acidic conditions. The degree of impoverishment is controlled by the intensity of leaching, that is the amount of water passing through the soil, and by the speed of return of materials to the soil via organic remains and the weathering of rock fragments.

Leaching and weathering may, therefore, be regarded as working in opposite directions. Leaching tends to deplete the soil's reserve of soluble materials (many of the major plant nutrients are in this category), while weathering tends to restore it. The reserve is furnished partly by the ions which are attached to the clay particles, partly by ions attached to colloidal organic particles (humus), and, of course, by the weatherable organic and mineral materials themselves. In the climate of upland Britain leaching is very intense and on almost all parent materials outstrips the effects of weathering so that the progressive development of strong acidity is inevitable. Variations in the rate of this development are discussed in the sections dealing with factors of soil formation.

Very intense leaching of well drained soils in the wettest parts of upland Britain leads to the progressive loss of silica from the breakdown of silicate minerals, with the residual accumulation of the oxides of iron and aluminium. Such *desilicated* soils are characterized by subsoils with a strongly ochreous brown colour and a very friable consistence (Crompton 1960).

1.1.4 Clay translocation

Clay particles, especially those less than about 0·0006 mm in diameter, are physically and chemically far more active than the sand and silt grains, and in certain conditions are mobilized within the soil. They may be carried in colloidal solution (suspension) by percolating water from an upper layer and be deposited in a lower layer, thereby producing a more or less pronounced textural change within the profile. The clay is deposited as linings to pores and coatings on peds. The process is sometimes referred to by the French term *lessivage*, and soils so affected are *sols lessivés*. Lessivage appears to be most strongly developed in soils which are relatively dry in summer and which are only slightly acid at depth. It is a striking feature of some soils formed over limestone on the North York Moors, but is unimportant elsewhere in upland Britain.

Some soils with a marked increase in clay content down the profile have little or no recognizable deposited clay in the lower layer. It is possible either that clay particles are being carried away in suspension without appreciable deposition at lower levels, or that chemical breakdown of clay minerals takes place with the formation of soluble components which are leached out. Thus the apparent loss of clay from the upper layer of many surface-water gley soils has yet to be adequately accounted for.

1.1.5 Podzolization

In this process iron and aluminium (often jointly referred to as sesquioxides) are translocated down the profile in well aerated conditions, that is in freely drained soils. Soil conditions become strongly acid and a thin layer of raw humus accumulates at the surface. Compounds released from the decomposing organic matter render sesquioxides soluble in the upper horizons and allow them to be washed downwards, leaving horizons consisting largely of bleached sand grains. Some of the sesquioxides are deposited in a thick diffuse subsoil horizon, usually beneath a layer of deposited humus material. Podzolization appears to be greatly facilitated by coarse textured soil materials rich in quartz grains. In some podzolized soils the subsoil horizons become somewhat cemented and hard as a result of the deposition of humus and sesquioxides. This effect is quite independent of the original consistence of the soil material, which may vary from loose through to very firm. The circumstances in which cementation takes place are not fully understood because many seemingly well developed podzols have friable subsoils.

1.1.6 Gleying

Well drained soils are characterized by free aeration and oxidizing conditions, but water in soils with restricted drainage may become stagnant because micro-organisms and plant roots use the dissolved oxygen faster than it can be renewed. Under the anaerobic conditions so produced, ferric iron is converted by the process of chemical reduction to the ferrous state. Ferrous compounds are highly soluble and are carried in solution through the soil until, on meeting oxidizing conditions again, they are re-precipitated in the ferric state. Upper horizons may progressively lose iron in this manner and develop a drab grey colour, while at lower levels in the soil iron may undergo localized redistribution producing intensely mottled coloration. Manganese compounds are affected in a similar way and give rise to black spots or flecks of re-precipitated manganese dioxide.

These processes, which are collectively referred to as gleying, vary throughout the year depending on the moisture status of the soil. Nevertheless, due to the fact that precipitation exceeds evapotranspiration for most of the year, and as parent materials conducive to slow vertical percolation are widespread, soils affected by gleying in some degree are the rule rather than the exception in upland areas.

Gleying occurs in soils in three different circumstances and as these are used to characterize three of the soil groups it is worthwhile describing them in some detail. The most common form of gleying in many upland areas occurs in soils where vertical drainage is impeded by a dense, massive* substratum, often but not invariably of clayey texture. Here the gleying is most intense in the upper soil horizons and leads to greyish colours due to the removal of iron in seepage water. Subsoil horizons develop strongly mottled colours due to the local redistribution of iron and manganese in seasonally fluctuating conditions. At still greater depths mottling decreases in intensity and the soil is noticeably less wet than above. Such a soil may be said to develop a seasonal "perched water-table", and is an example of the *surface-water gley group*.

Gleying also occurs in soils affected by ground-water. Here the soil material is often fairly permeable in itself and facilitates the seasonal fluctuation in the level of the ground-water table. Within the zone of fluctuation, ochreous mottling occurs as conditions are alternately aerobic and anaerobic, but there may be a net loss of iron to the ground-water. Sometimes, however, especially in basin sites, the concentration of dissolved iron builds up and leads to precipitation as bog iron ore in the zone of fluctuation. In the permanently waterlogged lowest layers bluish colorations may develop with the abundance of ferrous iron compounds. These soils form the *ground-water gley group*.

A third more or less distinct form of gleying occurs in soils which are periodically waterlogged at the surface yet adequately aerated beneath. When weakly developed this type of gleying produces grey patches within the otherwise normal topsoil, lower horizons being unaffected. On close inspection the grey areas are seen to be enclosed within very thin rusty coloured zones. Iron is mobilized in the ferrous state in the grey patches and by diffusion and re-precipitation is concentrated in the rusty border. When the gleying is strongly developed the grey patches merge into a horizon of greyish colour underlain by a continuous thin ironpan. Beneath the ironpan lies a relatively well-aerated brown coloured subsoil. Soils of this type are included in the group of *ironpan soils*; the characteristic process being referred to as *superficial gleying*.

1.2 FACTORS OF SOIL FORMATION

Soils are formed by the modification of the parent material by soil processes. The extent of the modification depends on the nature of the parent material, on past and present environmental factors such as climate, hydrologic conditions and vegetation, and on the length of time the processes have been acting. Human interference must also be taken into account.

1.2.1 Parent material

Soil parent material is defined as the original condition of the mineral material of the whole profile when first deposited or otherwise exposed to the action of the soil processes. Although the majority of parent materials in upland areas consist of superficial deposits rather than bedrock itself, the rocks from which the drifts are derived control not only the mineralogical composition but also to some extent the texture, stoniness and permeability of the materials. In addition the nature of the bedrock exerts a strong influence on the general topography which in turn affects the kinds of glacial and periglacial

deposits formed. As a result, an essential prerequisite to a consideration of soil parent materials is an appropriate classification of rocks. In this context the most important properties of rocks are conveyed by the term *lithology*, which refers to the mineralogical composition, grain size and hardness of the rock. The mode of formation of the rock, that is whether it is sedimentary or metamorphic, and whether the metamorphism involved heat or heat and pressure combined, or at what depth in the earth's crust an igneous rock crystallized from the molten state, is of much less concern to the pedologist than to the geologist. Tables 1.1 and 1.2 present a classification of rocks according to their lithology.

It is not considered appropriate here to

Table 1.1
Sedimentary and Metamorphosed Sedimentary Rocks
Predominant Grain Size

HARDNESS	SAND	MIXED	SILT	CLAY	CARBONATE
Unconsolidated (friable)	sands, gravels	loams	silts	clays	shell-sand, soft limestones
				marls	
Moderately hard	sandstones (pure), conglomerates	impure sandstones	silty-shales	clay-shales	limestones (oolitic or shelly) dolomites and chalk
Hard (including low-grade metamorphics)	quartzitic sandstones (psammites)	greywackes	silty-slates, argillites	clay-slates, argillites	hard limestones, hard dolomites (crystalline)
			(pelites)		
Very hard (high-grade metamorphics)	quartzites, granulites	quartz-mica-schists (semi-pelitic schists)	mica-schists (pelitic schists)	phyllites	metamorphosed limestones and marbles

Table 1.2
Igneous and Metamorphosed Igneous Rocks
Mineralogical Composition

VERY HARD	ACID	INTERMEDIATE AND BASIC	ULTRABASIC
Igneous	rhyolites, quartz-porphyries, granites	trachytes, andesites, syenites, diorites, basalts, dolerites, gabbros	peridotites, serpentines
Metamorphosed igneous	granite-gneiss	hornblende-schists	hornblendites

describe in detail the properties of each of these rock types; they may readily be found in the standard textbooks. Rather is it intended to assist the reader to identify at a glance the more important features of the types of rock commonly encountered in the geology literature, in the context of soil formation. In the columns of each table the rocks are grouped according to their approximate mineralogical composition. With increasing hardness rocks tend to give rise to parent materials of greater stoniness, greater permeability, and also (though less dependably) shallower depth. As applied to igneous rocks, the terms "acid", "intermediate", "basic" and "ultrabasic" refer to progressively decreasing proportions of silica in their composition. Soils developed from the ultrabasic rocks, although of uncommon occurrence, usually have special properties such as toxic levels of magnesium.

While it may be assumed that the finer grained sedimentary rocks and the less siliceous igneous and metamorphic rocks are capable of providing soils with higher nutrient levels than the more sandy or siliceous rocks, in most real situations physical factors such as depth to bedrock, consistence of the lower soil horizons and profile drainage class have more influence on the overall crop yield achieved.

This leads us to the consideration of the properties of superficial deposits or drifts as soil parent materials. The properties of most importance are the permeability to water and roots, the depth to bedrock, and the mineralogical composition. Of these, permeability is generally the most important and is the most predictable from the type of drift. Some drifts consist largely of very dense, firm material almost impermeable to water and roots. This material, which is usually referred to as "indurated"*, is the result of compaction by repeated freezing and thawing in periglacial conditions, and represents the relic permafrost layer. Indurated material is normally overlain by 30–75 cm of friable soil, which represents the former active layer. Drifts containing indurated material are very widespread in Scotland and may also be found locally elsewhere in upland areas. The properties of this material are described in more detail in the glossary.

Space does not permit more than a very brief consideration of the most important features of the common types of drift. More information about their mode of formation and general nature may be obtained from the textbooks; some of the latest ones are listed at the end of this paper. Table 1.3 presents a classification of superficial deposits as soil parent materials.

There is a common tendency to confuse the types of superficial deposit with the names given to the characteristic landforms in which they occur. Thus moraines and drumlins are mounds of till, eskers and kames are mounds of glacio-fluvial material, terraces may be formed from glacio-fluvial deposits, alluvium or solifluction drift, and so on.

Different kinds of drift may be deposited one above the other. Two or more distinct tills in vertical sequence may indicate multiple glaciation, and interglacial soils have been identified within such deposits. All gradations between glacio-fluvial material overlying till, through tills with resorted upper layers, to till which is little affected by meltwater are found in some regions. Colluvium almost invariably overlies one of the glacial or periglacial deposits.

1.2.2 Climate

The main elements of climate influencing soil development may be described as the wetness and warmth factors. In each case we are more concerned with the regimes of soil wetness and soil temperature than with the climatic variations which produce them.

Thus the wetness factor refers to the amount of water available for soil processes, and the duration of the period when the soil

Table 1.3
Superficial Deposits as Soil Parent Materials

DEPOSIT	MODE OF FORMATION	TOPOGRAPHY	STONES*	TEXTURE	INDURATION	DEPTH TO BEDROCK
glacial till (= boulder clay)	beneath ice-sheets or glaciers	gentle slopes	frequent, all sizes, subangular to sub-rounded	coarse-loamy to clayey, unsorted	present in loamy examples	usually 1–2 m occasionally much more
solifluction deposit (= slope drift or head)	periglacial:- solifluction = mass flow of active layer	mainly on steep or moderate slopes	abundant, all sizes angular unless till-derived	coarse-loamy to fine-loamy, unsorted	usually present in Scotland. Only in deepest examples in south	usually 60 cm – 2 m occasionally much more
glacio-fluvial deposits	deposited by glacial melt-water in sheets or mounds	gentle slopes in valley bottoms or on plains	abundant to rare, rounded	sandy or gravelly, well sorted and stratified	absent	variable, often over 2 m, but may be <1 m over till
glacio-lacustrine deposits	deposited by glacial meltwater in lakes	depressions (usually small and local)	usually absent	usually silty or clayey, sorted and stratified	usually absent	usually less than 2 m
scree	frost action and gravity (mainly during periglacial conditions)	usually steep slopes	abundant, sometimes very large, sometimes mainly small, angular	pre-dominantly stones, but slaty screes often have abundant fines	absent	variable, often over 2 m
colluvium	frost action, rain-wash and gravity; (post-glacial)	gentle to steep slopes	frequent to rare, usually small, subangular or subrounded	coarse-loamy to fine-loamy	absent	usually 30 cm–1 m but normally overlies another drift
alluvium	deposited by streams and rivers (post-glacial)	almost level, river flood plains	rare to frequent, but may overlie gravelly glacio-fluvial material	coarse-loamy, occasionally gravelly	absent	usually 60 cm–2 m

(*Continued overleaf*)

DEPOSIT	MODE OF FORMATION	TOPOGRAPHY	STONES*	TEXTURE	INDURATION	DEPTH TO BEDROCK
residual material	directly from underlying bedrock, frost action mainly in periglacial times	gentle or moderate slopes	abundant, all sizes, angular	coarse-loamy to fine-loamy	absent	usually thin, less than 60 cm
coastal sand	wind and tidal action (post-glacial)	almost level, usually on raised beaches	absent except in localized shingle areas	sandy	absent	variable on dunes, but usually > 2 m

is wet (or conversely when it is relatively dry), rather than to the total precipitation. By taking account of the losses due to evapotranspiration* we obtain the so-called *precipitation effectiveness* (precipitation minus evapotranspiration). This may be considered in terms of annual quantities or, probably better still, seasonally. Precipitation effectiveness (PE) varies more rapidly in relative terms from place to place than does rainfall itself, and this is particularly evident in the seasonal figures. While most places in the uplands experience a considerable excess of rainfall over evapotranspiration, even during the summer, the driest parts commonly record a moisture deficit (that is, a negative PE value) for the period April to September.

Green (1964a and 1964b) has computed *monthly* values of PE, and by adding together the values when PE is negative has obtained an accumulated *annual* average water deficit, which he calls *potential soil water deficit* (PWD). This is a measure of the maximum amount of drying the soil may experience, and the map of PWD can be related in a broad way to the distribution of well drained soils and poorly drained soils including peats.

Another measure of soil wetness which may be more relevant than total precipitation is the average annual number of rain-days (days with rainfall exceeding 0·25 mm) (Anon 1952). The distribution of deep peat throughout upland Britain has an apparently better relationship to the number of rain days than to total precipitation. Most deep peat is found where there are more than 225 rain days per annum.

The warmth factor is taken into account to some extent in the PE and PWD indices because the amount of evapotranspiration depends to a large extent on the atmospheric temperature regime. Anderson and Fairbairn (1955) and Fairbairn (1968) have used separate indices of wetness and warmth to produce a climatic zonation for forestry and agriculture. In 1955 summer rainfall was used as the wetness index, but in 1968 annual precipitation was preferred. The warmth factor used is the length of growing season, defined as the number of days when the mean temperature exceeds 6°C. It is not known, however, whether this is as relevant to soil development as it is to plant growth. An alternative index which takes into account not only the length of the growing season but also the temperatures reached during it, is the accumulated day-degrees above a specified minimum, e.g. 6°C (Macdonald *et al.* 1957). Soil temperature controls the rate of many processes, including the activity of the organisms concerned with the breakdown of organic material, as well as root growth and water absorption. The

significance of frost has been mentioned in connexion with the formation of parent materials. Contemporary deep freezing does not appear to be a feature of forest soils in this country but in the nursery, and wherever soils are exposed by cultivation, frost may have an effect on soil structure, in addition to creating the problem of frost-lift of small plants.

1.2.3. Topography

The influences of topography considered here are the indirect effects on soil wetness and temperature through the modification of climate, and the direct effects on soil wetness via run-off and seepage.

The relationship of altitude to rainfall is very close and direct, the only important variation being the rate of increase of rainfall with altitude, which is greater in the west than in eastern areas. As temperature decreases with altitude, the overall effect on PE or PWD is accentuated.

The effect of aspect on soil formation is quite marked on steep slopes but is often obscured by the influence of other factors which may also vary in a particular landscape. Given relatively uniform parent materials and similar angles of slope it is evident that superficial gleying is favoured by north and north-east aspects. This is particularly well seen in the steep-sided valleys of mid Wales where brown earths on the south-facing slopes contrast with ironpan soils on the north-facing slopes.

Angle and shape of slope influence soil development through their control over the hydrologic conditions at different positions in the landscape. Redistribution of soil water by run off and seepage sets up a hydrologic sequence (Glentworth and Dion 1949) extending from hilltop to valley bottom and which in the ideal case has several members. On the hilltop run off is slow and soils are periodically waterlogged with gleying symptoms and perhaps peat formation. On the steepest mid-slope position rapid run off and seepage within the profile usually maintain well drained soils. At the bottom of the slope in basin sites the accumulation of soil water favours gleying and peat formation. Intermediate positions in the sequence may also be distinguished, but it is easy to over-stress the idealized case. It is in fact unusual to find soils representative of more than two or three members of the sequence on any slope, due to the rarity of the perfect convexo-concave shape, and also due to changes in parent material.

1.2.4 Vegetation, soil organisms and man

Plant communities partly determine the nature of the organic horizons and the manner in which the material is acted upon by organisms, but it is questionable how far this can be considered a primary effect upon the soil. It is becoming increasingly evident that it is more valid to regard vegetation and the population of soil organisms as secondary factors, dependent upon the primary factors of parent material, climate and topography. There are, nevertheless, some striking examples of changes in soil processes which appear to have resulted from changes in vegetation brought about quickly by man's activities.

The increase in soil wetness resulting from deforestation during Bronze Age times appears to have been responsible for the development of superficial gleying within formerly well drained soils on the North York Moors (Dimbleby 1962). Crampton (1965a) has suggested that a similar process commenced during medieval times with the spread of heathy vegetation at the expense of woodland on some sites in South Wales. The reversal of the downward trend in the extent of woodland which has been the feature of the last fifty years or so, through the re-afforestation of heathland and moorland sites, is undoubtedly bringing with it a dramatic change in the course of soil development of these areas. "Soil improvement" as carried out by the forester means increasing the productivity for

the planted trees, and to that extent the changes that he tries to make may be considered "beneficial" in a general sense. Since most soil processes taking place in undisturbed soil under present conditions appear to be leading to a lowering of soil productivity, soil improvement practices are usually aimed at slowing down or reversing the natural tendencies.

1.2.5 Time

When considering the time factor in soil development we should note that our soils are largely of post-glacial origin and that they are immature by the standards of some tropical soils. Nevertheless they have experienced a series of climatic fluctuations which must have altered the nature and rate of the soil processes. The period of periglacial climate following the waning of the ice sheets is widely recorded in the occurrence of permafrost, ice wedges* and other features typical of present day tundra soils. The effects of subsequent climatic fluctuations on mineral soils are less well known, although some idea of their magnitude can be deduced from the great changes in the vegetation which are known to have occurred. The variations in the rate of accumulation of peat bogs are well documented, although ascribing causes is more difficult than it might at first appear, in view of the lack of agreement as to the reason for the present phase of peat erosion.

1.3 SOIL HORIZONS

The actions and interactions of the soil processes as controlled by the factors of soil formation lead to the differentiation of soil horizons roughly parallel to the surface and differing from each other in such features as colour, texture, structure, type and amount of organic matter, degree of root development or faunal activity. The whole system of horizons lying more or less within the zone penetrated by plant roots constitutes the soil profile, and the material in which the horizons have developed is termed the *parent material.* The relatively unaltered material present at depth can sometimes be regarded as equivalent to the parent material: commonly, however, soils developed in drifts inherit stratification from the original material and this sort of deduction may be invalid.

There are, unfortunately, a number of systems of classification and notation of soil horizons in use in this country at the present time, and it is not possible to predict which of these, if any, will become generally accepted. Most of the systems are based on the traditional A,B,C scheme, with various modifications. Most distinguish 3 to 6 master horizons, designated O,A,B,C etc., but there are several ways of designating the subdivisions, either using letter suffixes, numbers or both. The most comprehensive horizon classification yet attempted is that of FitzPatrick (1967), who abandons the hierarchical system involved with the A,B,C nomenclature and gives each definable horizon equal status and its own name. It has been decided for present purposes to use only a classification of master horizons to aid the characterization of soil groups in Chapter 2.

O horizons – horizons containing more than 20 per cent organic matter. Usually subdivided into Ol litter, Of fermentation layer and Oh humified layer.

A horizons – upper mineral horizons with relatively dark colours due to the incorporation of humified organic matter as a result of biological activity and/or cultivation.

E horizons – horizons with paler colour and lower organic matter content than overlying A horizons, and a lower content of organic matter and/or iron oxide and/or clay than the immediately underlying (usually B) horizon.

B horizons – subsoil horizons differentiated by colour and/or structure from overlying A or E horizons and underlying C horizons, and characterized by an accumulation of clay and/or humus and/or iron oxides resulting from weathering in situ or translocation from above.

C horizons – mineral substrata other than bedrock which underlie A, E or B horizons and which have undergone little alteration other than physical weathering or gleying due to groundwater. They are normally structureless or have platy structure.

R horizons – hard, consolidated bedrock, little altered except by fragmentation in situ, and which it is impracticable to dig.

g (suffix) – gleyed horizons are indicated by adding the suffix g to the A, E, B or C notation.

Other suffixes which are frequently used include:

Bh for the humus deposition layer of podzols,

Bs or **Bfe** for the sesquioxide deposition layer of podzols,

Bt for the clay-enriched layer of *lessivé* soils, and **x** for indurated layers.

BROWN EARTH

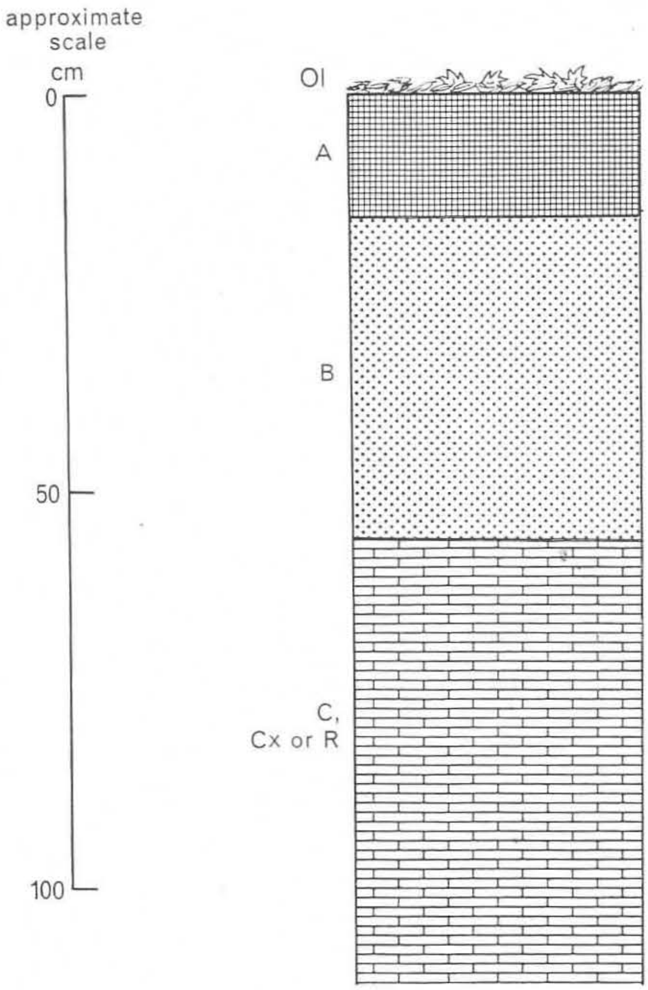

Fig. 2. Profile of a typical brown earth. See Plate 2, page 24, for colour photo, and text, para. 2.1, for description.

PODZOL

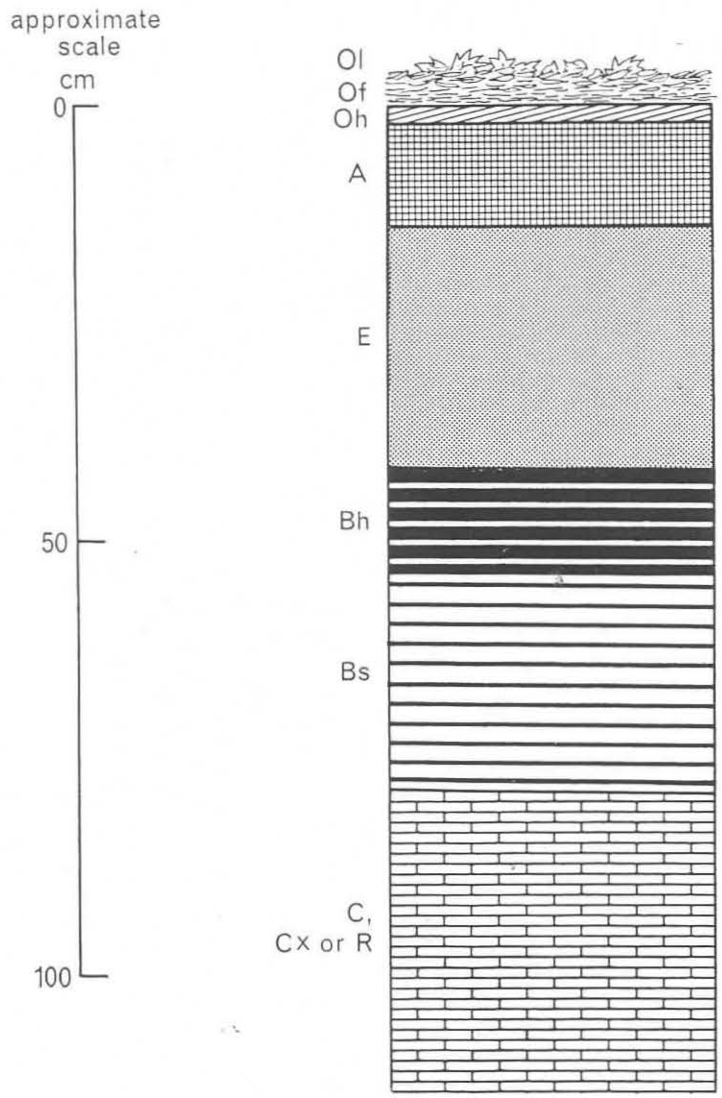

Fig. 3. Profile of a podzol. See Plate 1, page 1, and Plate 4, page 26, for colour photos, and text, para. 2.2, for description.

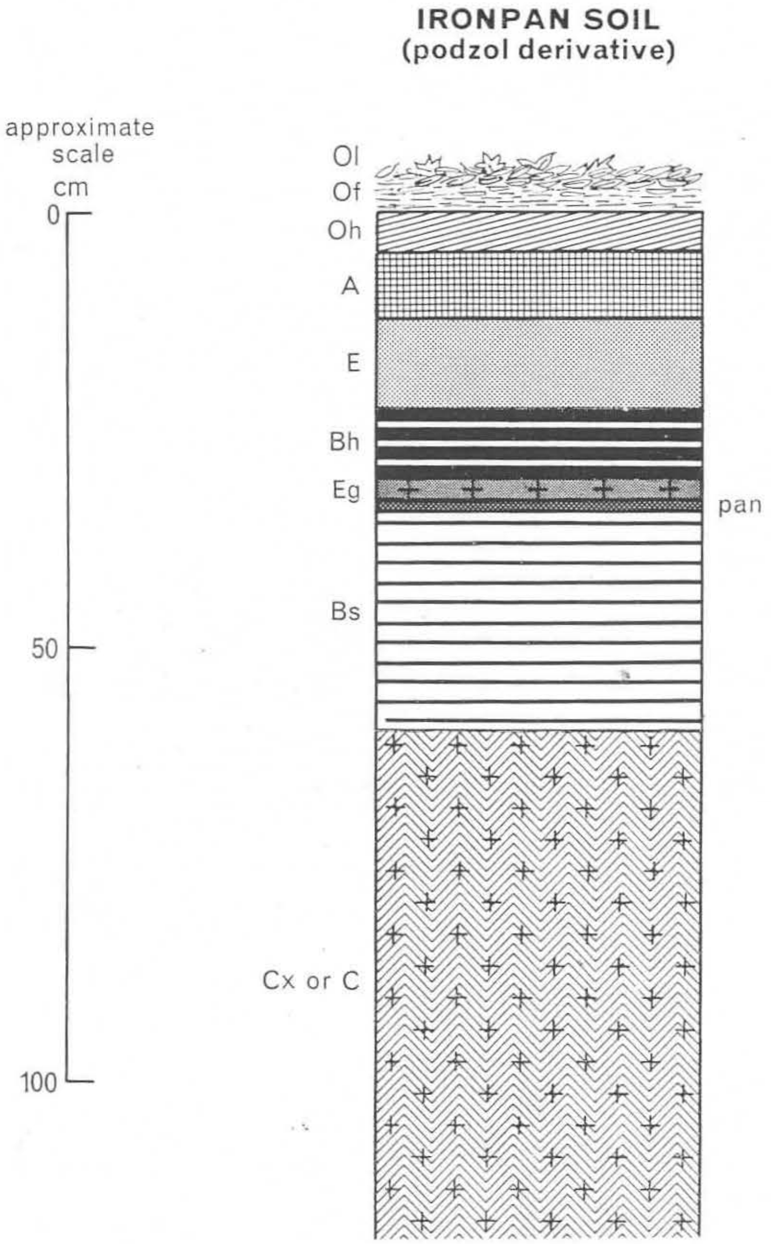

Fig. 4. Profile of an ironpan soil, podzol derivative. See Plate 5, page 27, for colour photo, and text, para. 2.3, for description.

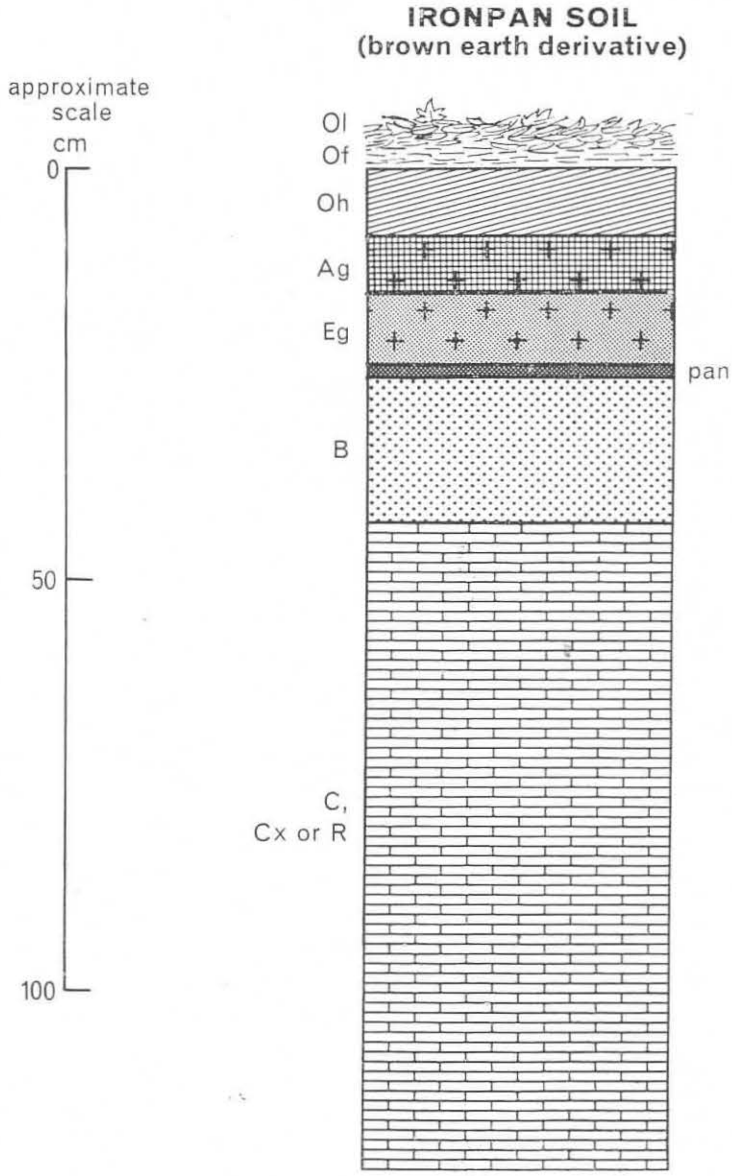

Fig. 5. Profile of an ironpan soil, brown earth derivative. See Plate 6, page 28, for colour photo, and text, para. 2.3, for description.

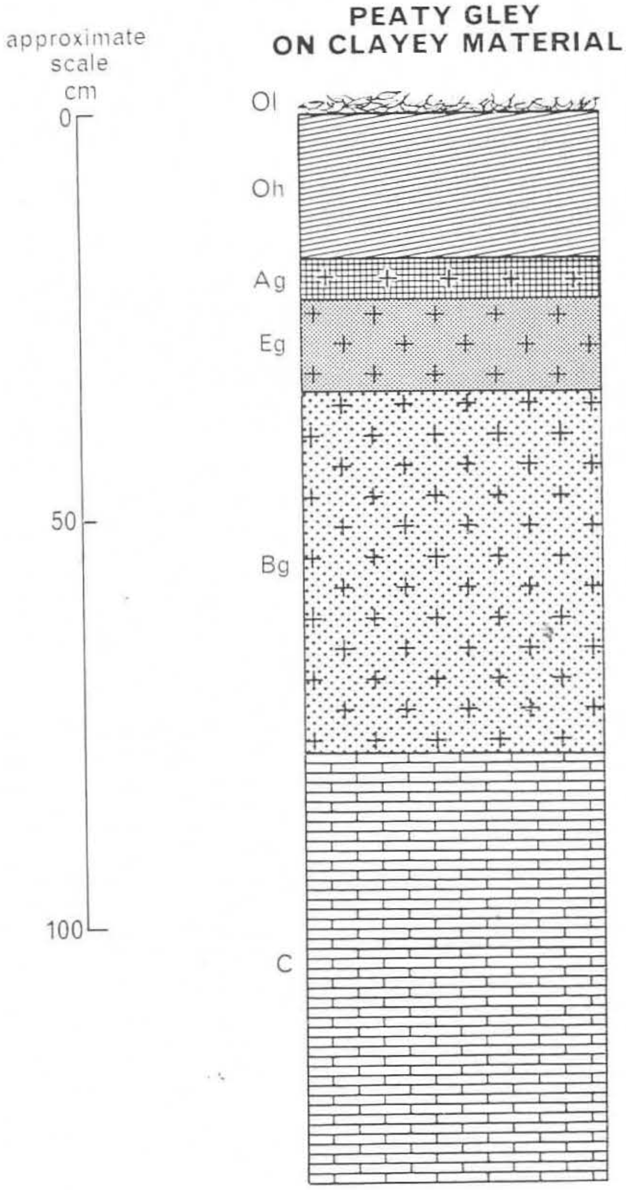

Fig. 6. Profile of a peaty gley on clayey material. See Plate 8, page 30, for colour photo, and text, para 2.4(a), for description.

SURFACE - WATER GLEY ON INDURATED MATERIAL

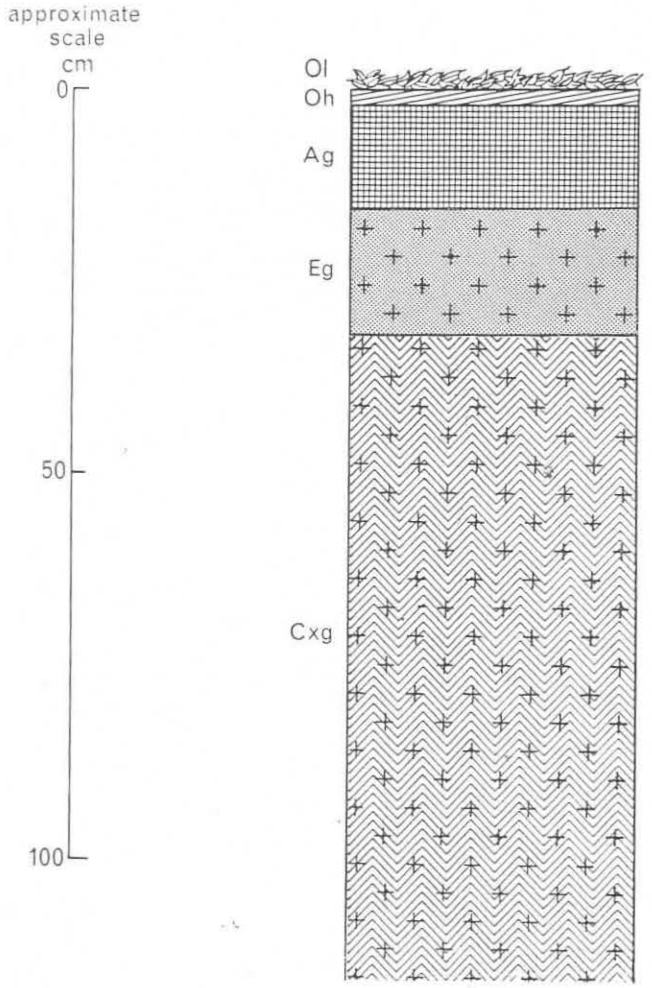

Fig. 7. Profile of surface-water gley on indurated material. See Plate 9, page 31, for colour photo, and text, para. 2.4(b), for description.

GROUND-WATER GLEY

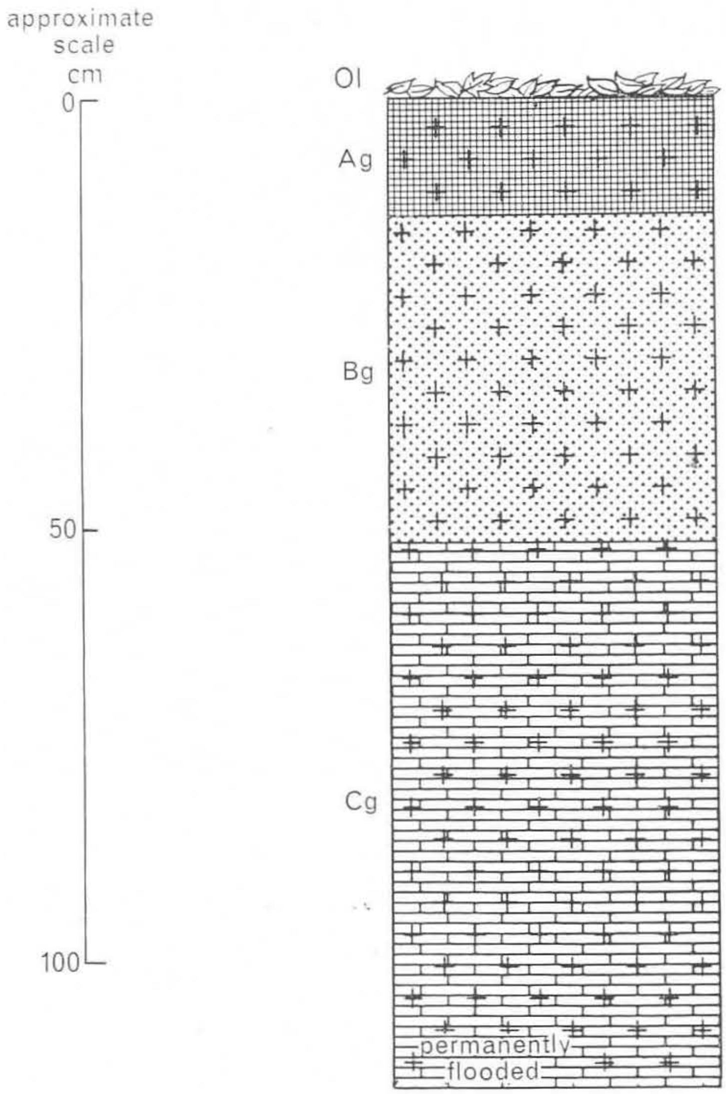

Fig. 8. Profile of ground-water gley. See text, para. 2.5, for description.

ARGILLIC BROWN EARTH
(SOL LESSIVÉ)

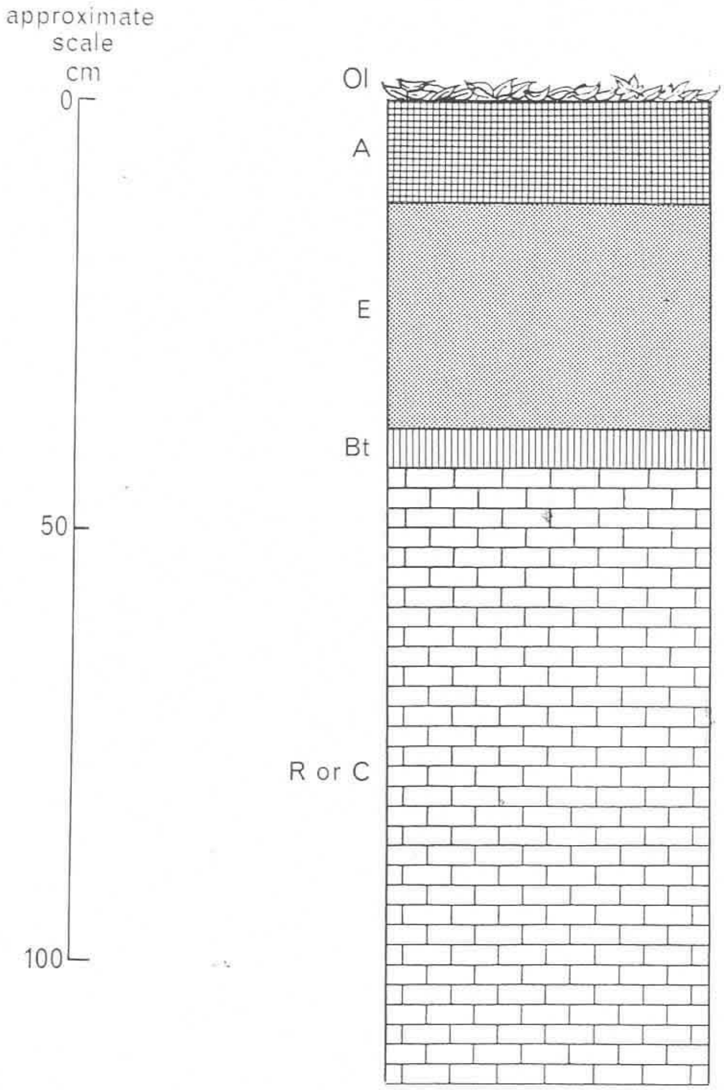

Fig. 9. Profile of argillic brown earth (sol lessivé). See Plate 11, page 33, for colour photo, and text, para. 2.7, for description.

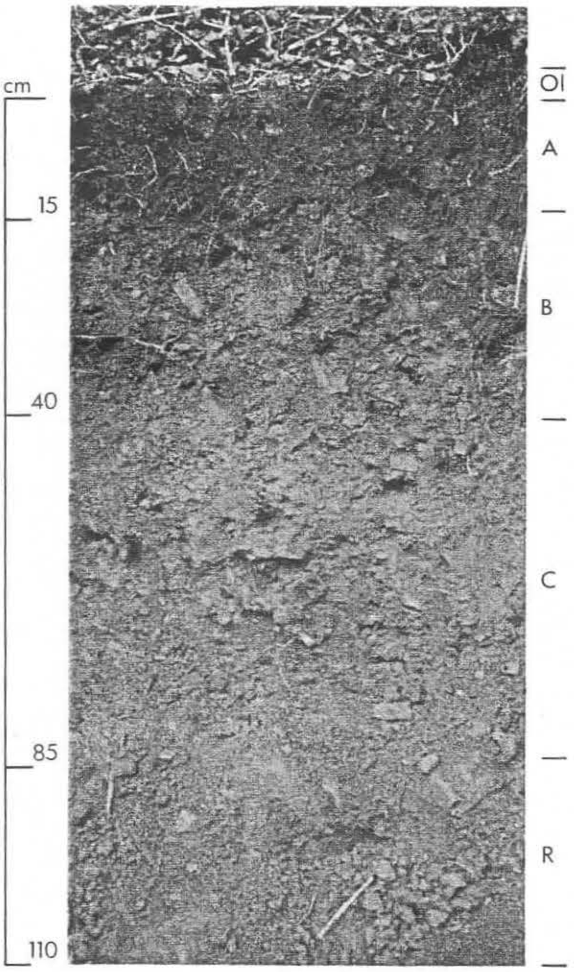

PLATE 2 NORMAL BROWN EARTH
A deeply rootable highly productive soil derived from slaty rock of the Carboniferous Culm Measures in Devon. An excellent forest soil whose only major limitations are the tendency to weediness and, at this site, the steepness of slope. See Figure 2, page 16, for diagram and text, para. 2.1, for description.
Hartland Forest, Devon.

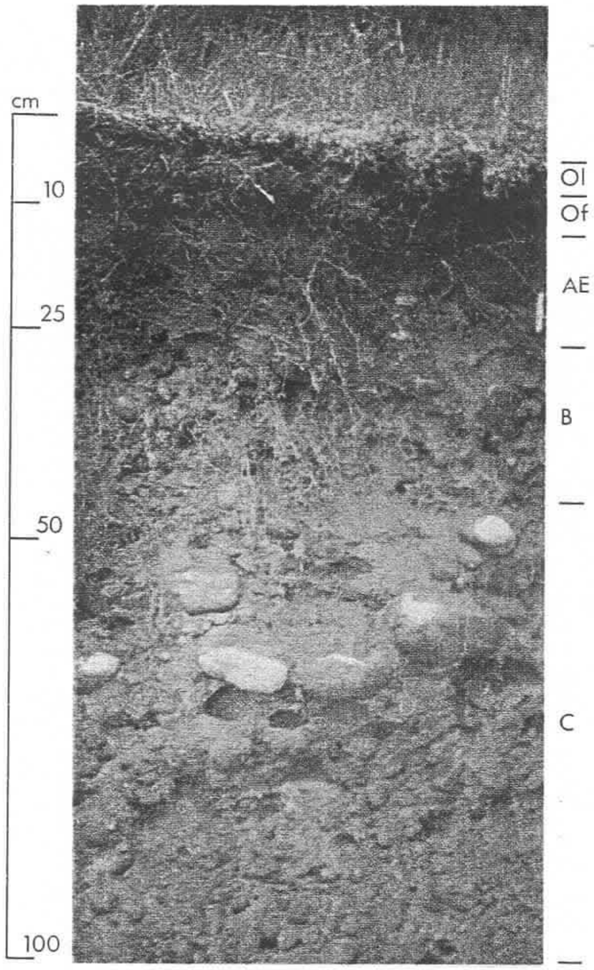

PLATE 3 **PODZOLIZED BROWN EARTH**
A brown earth developed in very coarse-textured material, a glacio-fluvial gravelly sand. There is a distinct surface organic layer and abundant bleached sand grains in the AE horizon. A deeply rootable and productive soil. See text, para. 2.1.2, for description. Elchies Forest, Morayshire.

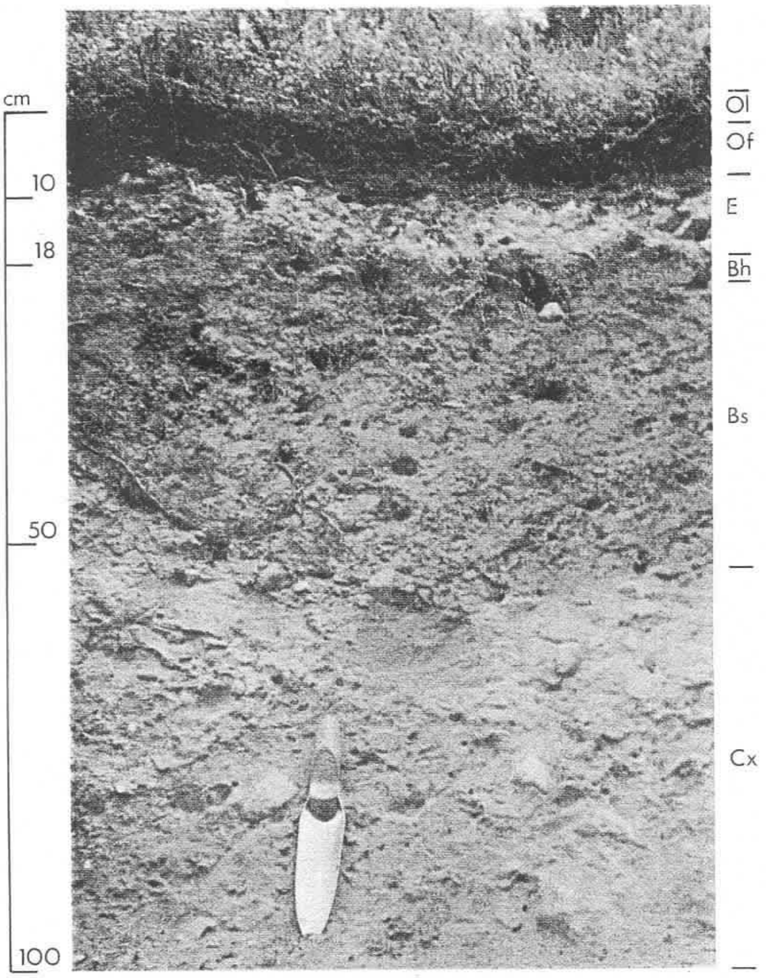

PLATE 4 **PODZOL ON INDURATED MATERIAL**

A podzol developed on loamy morainic till, with a well developed indurated layer. The E horizon is relatively thin and the Bs horizon is friable, probably due to the loamy texture. Roots are absent from the indurated material. Although providing only shallow rooting, this freely drained soil is capable of producing good crops of Douglas fir and Sitka spruce if the problem of ericaceous vegetation is overcome. Some windthrow may occur late in the rotation. See text, para. 2.2, for description. Culloden Forest, Inverness-shire.

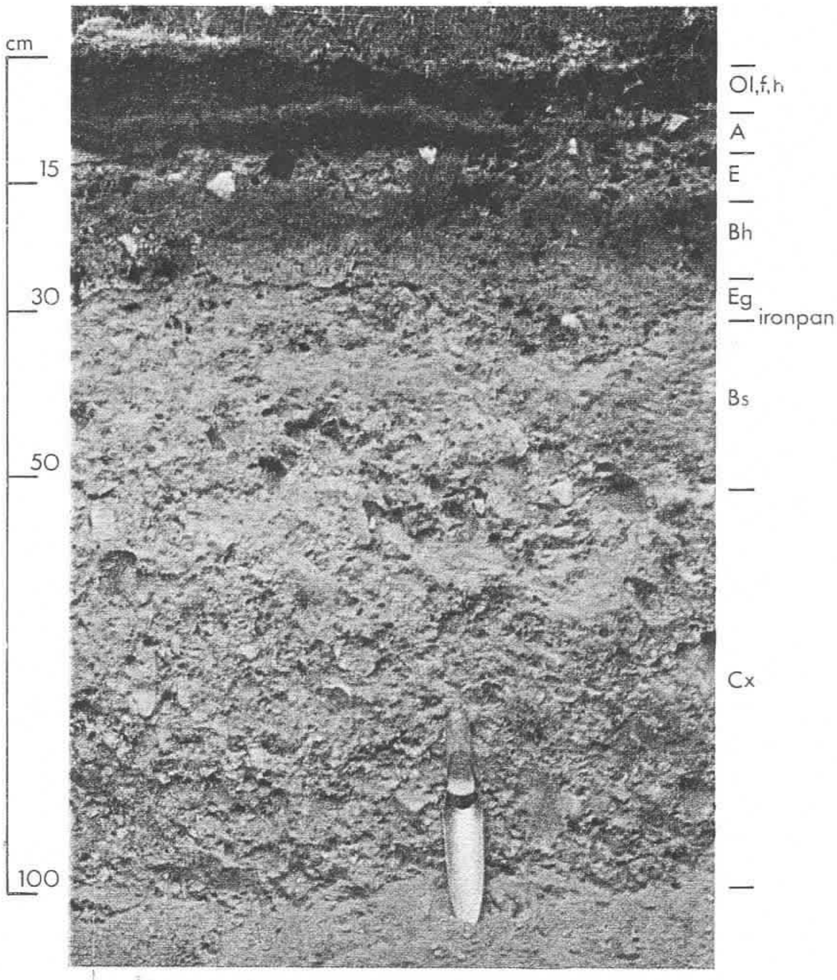

PLATE 5 **IRONPAN SOIL, PODZOL DERIVATIVE, ON INDURATED MATERIAL**
This soil is developed on deeply weathered conglomerate rock of Old Red Sandstone age. The bright red colour of the C horizon is produced by an oxide of iron, but is of no particular significance in soil formation. The yellowish or olive hue of the Eg horizon is indicative of gleying processes resulting from waterlogging above the ironpan. The E, Bh and Bs horizons are inherited from the former podzol profile. The Oh, Eg and ironpan are more recent developments. With deep cultivation, the vertical drainage and the productivity of this soil are greatly improved. See Figure 4, page 18 for diagram, and text, para. 2.3, for description. Teindland Forest, Morayshire.

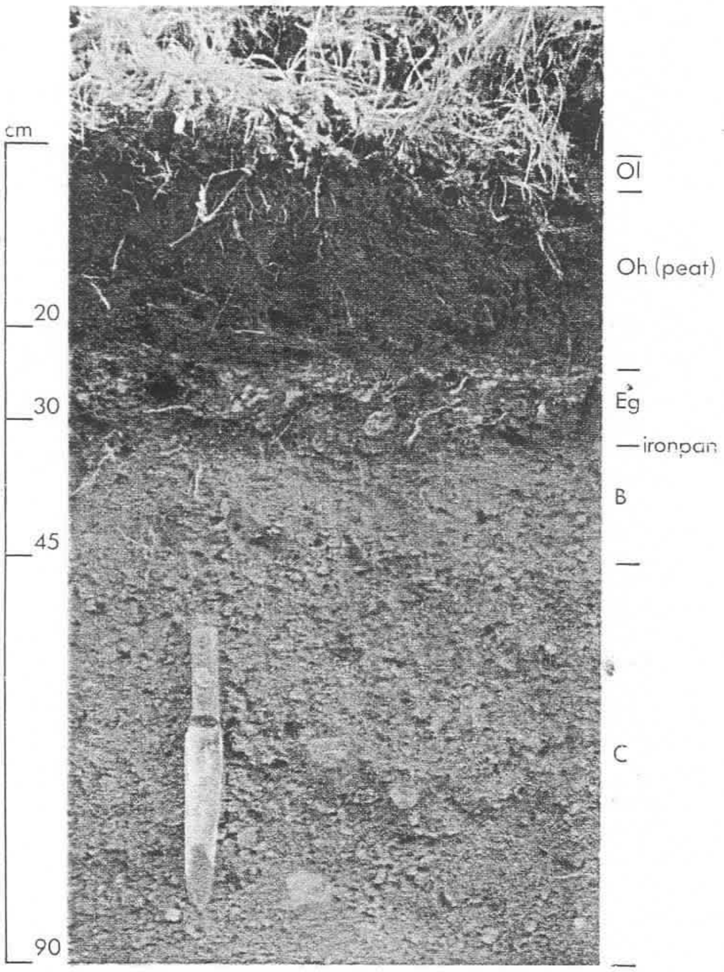

PLATE 6 **IRONPAN SOIL, BROWN EARTH DERIVATIVE**
The parent material is a solifluction deposit derived from greywacke and slate of Silurian age. In this type the ironpan is often very thin but it is usually effective as a barrier to the percolation of water and to root penetration. A thick development of peat partly reflects the high rainfall of many of these areas. The B and C horizons are friable and permeable, and given cultivation to rupture the pan this soil is deeply rootable. See Figure 5, p. 19, for diagram, and text, para. 2.3, for description. Forest of Ae, Dumfries-shire.

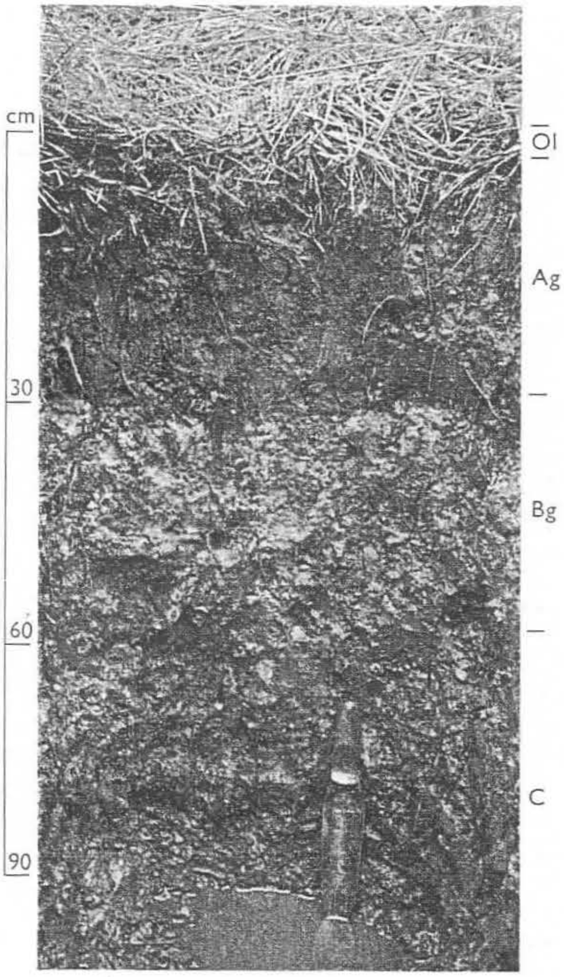

PLATE 7 **SURFACE-WATER GLEY ON CLAYEY MATERIAL**
This soil is developed in clayey glacial till derived from Carboniferous sediments. The till has a uniform dark greenish grey colour, although in the illustration this is partially obscured by water running down the profile face from overlying horizons. Gleying has produced a mottled yellow and pale grey colour in the Bg horizon and an overall drab grey in the Ag. See text, para. 2.4, for description. Harwood Forest, Northumberland.

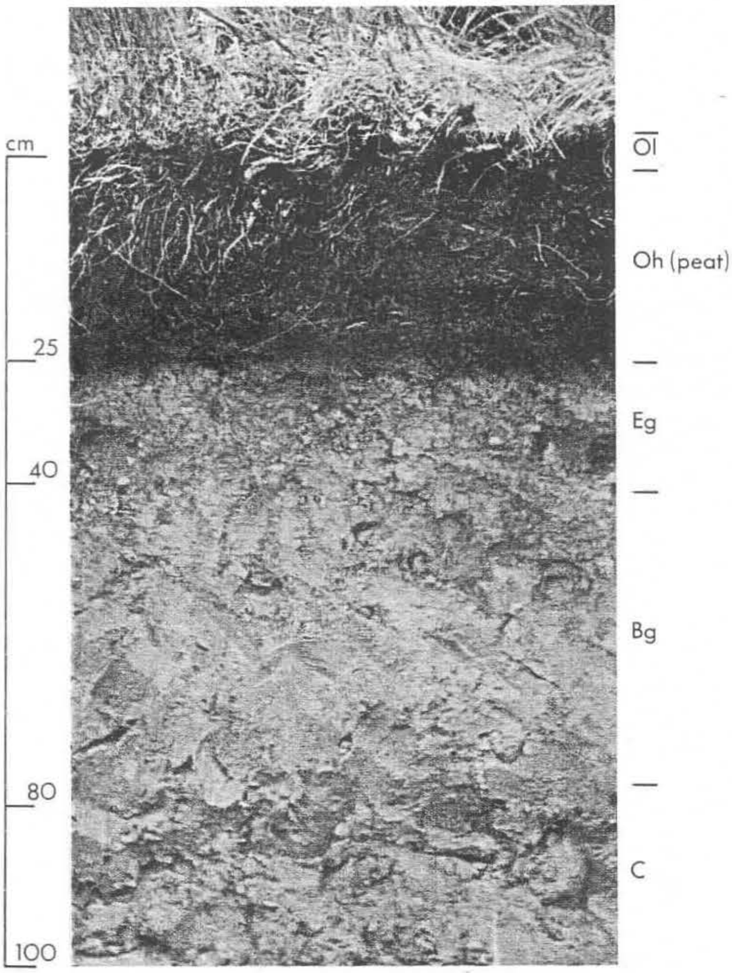

PLATE 8 **PEATY GLEY ON CLAYEY MATERIAL**
This soil is developed in clayey glacial till derived from Carboniferous sediments. The till has a uniform dark greenish grey colour in the C horizon but is modified by gleying processes in the Bg and Eg horizons where there is seasonal waterlogging. Deep drains are able to intercept excess water moving laterally in the occasional fissures which extend to the base of the Bg horizon. Without improved drainage this soil has a high windthrow hazard. See Fig. 6, page 20 for diagram, and text, para. 2.4(a), for description.
Kershope Forest, Cumberland.

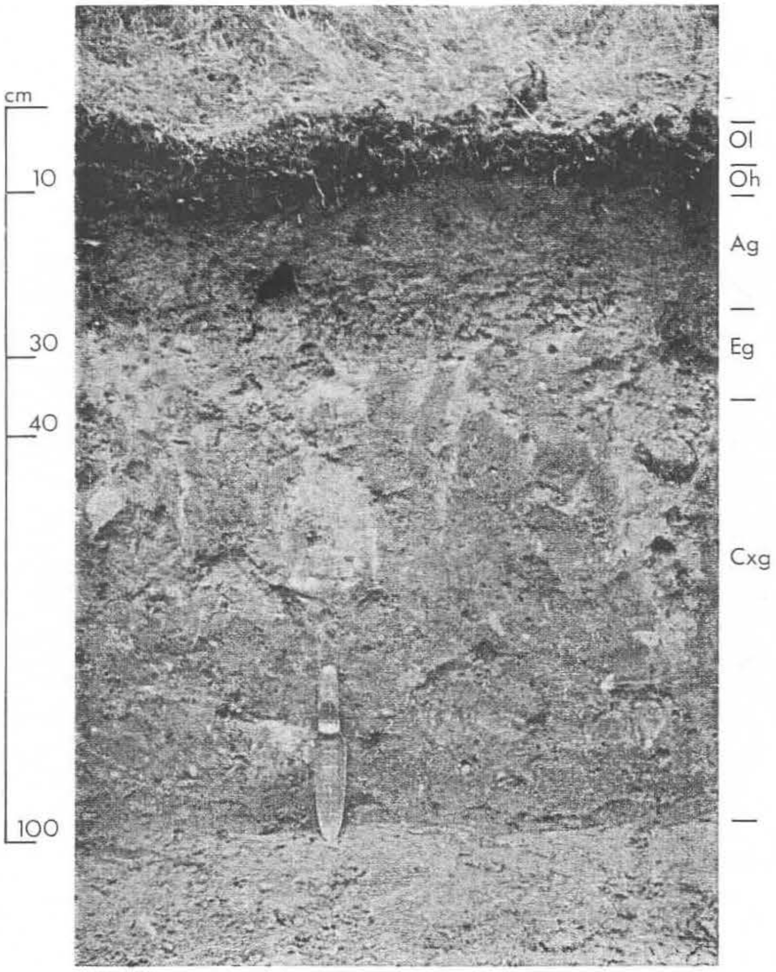

PLATE 9 SURFACE-WATER GLEY ON INDURATED MATERIAL
This soil is developed in glacial till derived from Old Red Sandstone sediments. The strong red colour of the parent material facilitates the diagnosis of gleying effects in the profile. The grey vertical streaks and patches result from gleying extending from a system of fissures within the indurated layer. Deep drainage is the prime necessity both for the growth and long-term stability of the tree crop, but deep cultivation may also be required if root exploitation of the dense Cxg horizon is to be achieved. See Figure 7, p. 21, for diagram, and text, para. 2.4(b), for description. Black Isle Forest, Ross-shire.

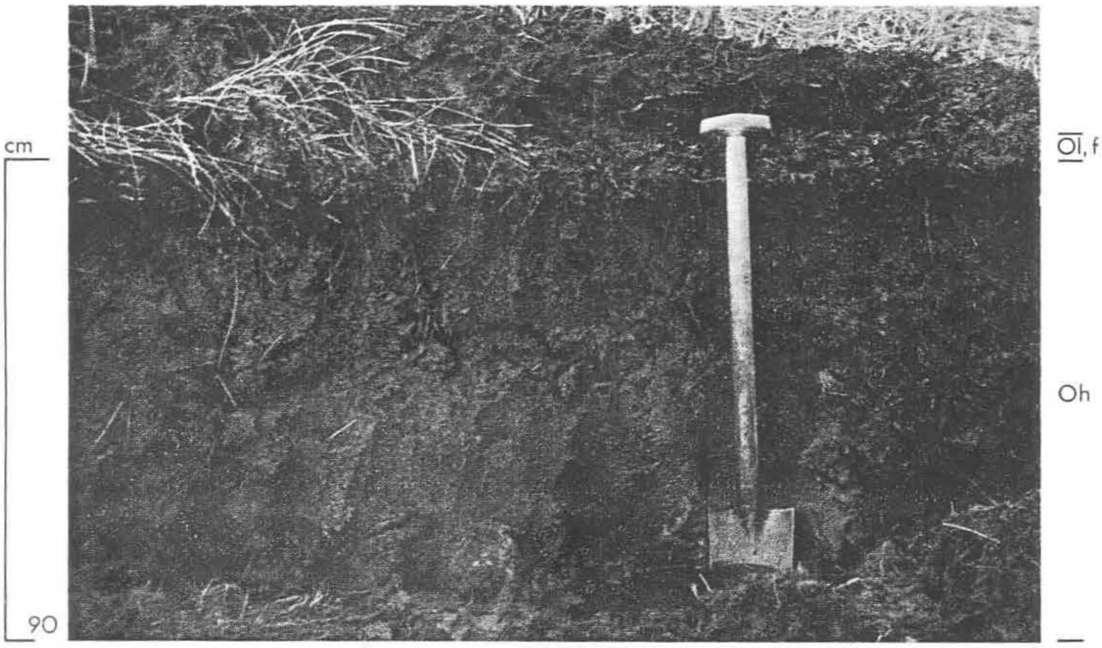

PLATE 10 **FLUSHED BASIN PEAT**

This type of peat is black or dark brown in colour, highly humified and rarely much more than 1 metre in depth. The vegetation includes tall rush species (*Juncus*). Spruces grow well on this peat, which has a relatively low fertilizer requirement. See text, para. 2.6, for description. Glen Trool Forest, Kirkcudbrightshire.

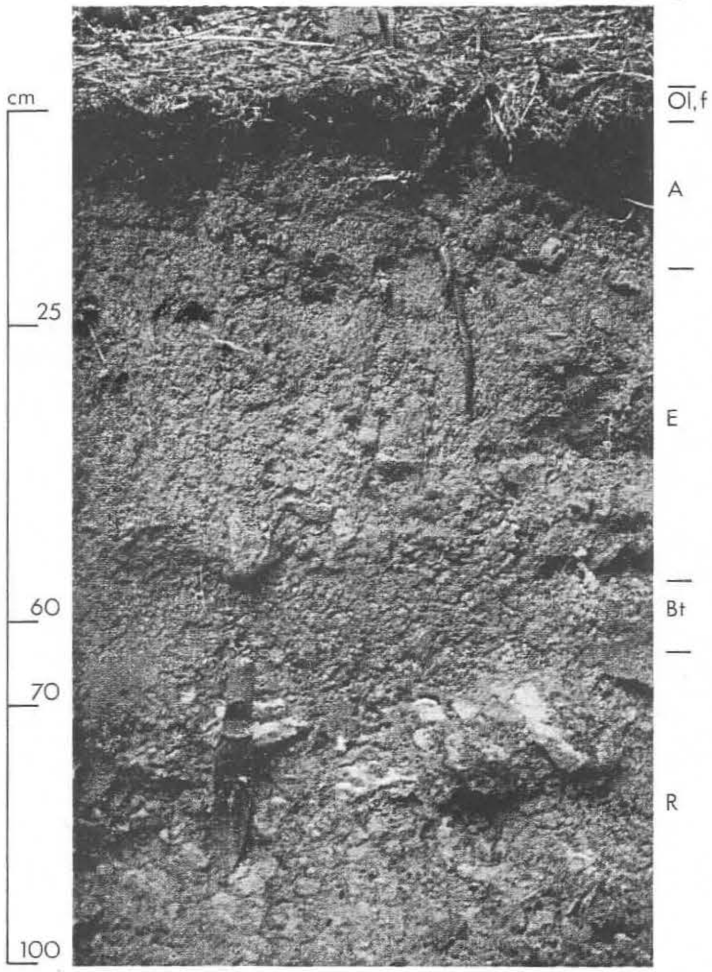

PLATE 11 **ARGILLIC BROWN EARTH**
This soil is developed in a loamy drift overlying oolitic limestone of Jurassic age. Provided the depth of soil is not too limited, these soils are highly productive, and have only a potential weediness problem. See Fig. 9, p. 23 for diagram, and text, para. 2.7, for description. Dalby Forest, Yorkshire.

SOIL GROUPS

As explained in the Preface, this paper is intended to serve as a basis for improved communication until the preparation of a comprehensive classification and field manual is possible. Partly for the sake of brevity and partly to avoid possible differences of classification between this paper and the proposed manual, only the soil groups are defined here. Those who look for absolute precision in the definitions will be disappointed. No attempt has been made to cover all known profile variations or to employ many quantitative criteria for differentiation. It is considered more important to establish the qualitative differences clearly than to provide a set of unambiguous classes with rigidly defined limits. Quantitative criteria have the disadvantage that they tend to require changing with developments in the technology of soil use.

In the discussion of each soil group, the first paragraph consists of the definition of the typical member, the second paragraph describes the common intergrading situations between groups, the third considers the distribution of the soils, and the fourth discusses the forestry properties of the group. Colour photographs are included to illustrate a few of the variations of profile type and parent material encountered in upland Britain.

2.1 BROWN EARTHS (Fig. 2, Plate 2)

2.1.1 Definition

These are soils typified by brownish or reddish colours, free drainage and moderate or strong acidity, throughout the profile. Humified organic matter is incorporated into the mineral soil to give a dark brown A horizon. There is no E horizon. The B horizon is distinguished from the underlying C by a richer brown colour due to weathering and the residual accumulation of iron oxides. The A and B horizons have a crumb or small blocky structure and are of friable consistence. The soils are usually somewhat stony, but rarely extremely so, and have textures ranging from coarse-loamy to fine-loamy. The C horizon may either be unconsolidated and friable, or it may be very stony and merge into bedrock, or it may consist of indurated material.

2.1.2 Intergrading Situations (Plate 3)

Intergrades between brown earths and podzols are important on coarse textured parent materials. They generally have thin raw humus accumulations and partially bleached A/E horizons. The B horizons may have slight enrichment of sesquioxides through podzolization but in the field may be indistinguishable from horizons rich in sesquioxides due to weathering alone. Intergrades with ironpan soils, surface-water gleys and ground-water gleys are described as brown earths with (slight) gleying if the predominant colours of the profile are brownish, with grey and ochreous mottles subordinate. Some of the members of the soils on calcareous rock groups have many of the characteristics of brown earths.

2.1.3 Distribution

The development of brown earths is favoured by base-rich rocks, permeable loamy textured drifts, steep slopes, low rainfall and low altitude, and southerly aspect.

Brown earths are particularly well developed and widespread on basic and intermediate igneous rocks, and on the metamorphosed fine-grained rocks including slates, mica-schists and phyllites. Solifluction deposits, which occur on moderate or steep slopes, are by far the most important kind of drift, but occasionally brown earths are developed on tills, glacio-fluvial deposits, fine scree or

residual materials. The effects of climate are tempered by topography and parent material. Thus brown earths may be abundant in high rainfall areas because of steep slopes and permeable loamy drifts. They are generally restricted to altitudes below about 300 m, although rarely reaching this in northern Scotland, but on the other hand may extend up to 425 m on south facing slopes in Wales.

2.1.4 Forestry Properties

Brown earths provide many of the best soils available for forestry in upland Britain. Free drainage and friable consistence allow intensive rooting through the A and B horizons, and when induration is absent, often through the C horizon also. Nutrient levels are adequate for satisfactory growth, and fertilization at planting is not generally practised. This does not preclude the possibility that worthwhile responses to phosphate or other nutrients may be obtained later in the rotation, but evidence for this is at present very limited. The most frequent deficiency of brown earths in upland areas is a lack of rootable depth. This may be due to shallowness to bedrock, especially when the parent material is residual, or to the presence of an indurated C horizon. When overlying shallow bedrock, brown earths may have inadequate moisture storage capacity for some species. When indurated material is present, moisture shortage is less likely to be a problem because of the lateral seepage which takes place on the upper surface of the layer, seepage which is often nurtured by water retentive peaty soils on the upper part of the slope. Many soils that are shallow to bedrock, and most of those with indurated layers, do not provide adequate rooting depth for the stability of mature crops in exposed situations. Some recent estimates of the windthrow hazard pertaining to different soil types in Wales have been expressed in terms of the likelihood of severe damage occurring before or after 18 m top height. (Pyatt *et al.* 1969.) Brown earths are usually weedy sites, growth being vigorous and the variety of weed species very wide, but heather (*Calluna*) and blaeberry (*Vaccinium*) are rarely present in quantity. The most characteristic species are bracken, bramble, Yorkshire fog, wavy hair-grass, bent and fescue.

2.2 PODZOLS (Fig. 3, Plate 1 (cover) and Plate 4)

2.2.1 Definition

Podzols are freely drained, strongly acid soils with a surface accumulation of humus, an E horizon from which iron oxides have been removed, and B horizons in which translocated humus and iron oxides have been deposited. The A horizon, which may not be particularly well defined, consists of blackish humus particles mixed with bleached sand grains. The E horizon consists largely of bleached sand grains and has a whitish colour. Both A and E horizons have a very friable consistence. The upper part of the B horizon contains deposited humus and sesquioxides, and has a black or very dark brown colour. The lower part contains sesquioxides with less humus and is dark brown in colour. Podzol B horizons are often rather cemented and may constitute a partial impediment to intensive and further downward rooting. The C horizon is usually paler in colour than the B horizons. It is either unconsolidated and friable, or very stony and merging into bedrock, or is indurated. Textures are sandy or coarse-loamy.

2.2.2 Intergrading Situations

Soils which have many of the above features but which also have a thin ironpan (occurring between the humus deposition layer and the main sesquioxide layer of the B horizon) are included within the ironpan soils group. Intergrades with brown earths have already been mentioned. Intergrades with surface-water gleys are usually included in that group.

2.2.3 Distribution

Podzols as defined here are largely restricted to sandy or gravelly materials and to altitudes below about 230 m.

Sandy or gravelly materials are predominantly derived from the coarse textured sedimentary and metamorphic rocks and the "acid" igneous rocks. The most extensive examples of these are sandstones of the Old Red Sandstone, Carboniferous and Jurassic systems, quartzites and quartzose schists of the Moine and Dalradians, and granites. Glacio-fluvial deposits are the most typical kind of drift, but occasionally tills and solifluction deposits give rise to podzols. A few years ago it appeared to the author that podzols were largely restricted to eastern Britain and that this might have reflected a climatic influence. It now seems more likely that the distribution is much more closely linked to quartzose sandy parent materials than to, say, low rainfall areas. Nevertheless, there is a strong tendency for podzols to intergrade to ironpan soils with increasing altitude, and this change usually takes place by about the 230 m contour, and usually well before this in the north and west of Scotland. Steep slopes favour podzols as against ironpan soils, presumably because superficial gleying is reduced. This relationship is well demonstrated on the North York Moors.

2.2.4 Forestry Properties

Although in many classifications soils with ironpans have been grouped with podzolized soils, the distinction is important from a forestry standpoint. Free drainage and the relatively good conditions for rooting are the most important features of the true podzols, and suggest a stronger link in practical terms with the brown earths. The strong acidity and the low nutrient levels of many podzols rarely appear to represent a limitation to the growth of the major coniferous species, and yields are usually as high as on adjacent brown earths. No doubt intensive deep rooting compensates for deficiencies in nutrient content per unit volume, and for low water holding capacity. Where rainfall is low, the growth of species with high moisture demands is invariably better on deeply rootable sandy podzols than on nearby clayey surface-water gleys, and what is often even more important, crop stability is much greater. Podzols are characteristically heathery, but there are often grasses present. Following ploughing, grasses usually become temporarily dominant, followed within a few years by vigorous heather (*Calluna*) regrowth which may cause check in sensitive species.

2.3 IRONPAN SOILS (Figs 4 and 5, Plates 5 and 6)

2.3.1. Definition

The essential features of this group are the presence of an Eg horizon which is waterlogged for substantial periods of the year and which rests sharply on a thin ironpan. There may be a peaty Oh horizon, thicknesses up to 45 cm being allowed within the definition. The ironpan usually overlies a friable brownish coloured B horizon similar in appearance either to the subsoil of a brown earth or that of a podzol, and evidently relatively well aerated. This in turn may be followed by indurated material. In some examples a strongly developed, rather deep-lying ironpan rests directly on the indurated layer. Ironpan soils are strongly acid throughout the profile.

2.3.2 Intergrading Situations

Intergrades with brown earths, podzols or surface-water gleys (including peaty gleys) are sometimes extensive, and are usually included in the ironpan soils group in soil survey. They generally have a very thin or discontinuous pan together with partially expressed features of the other group to which they are related. Transition zones between ironpan soils and hill peat (see Deep Peat group) are not usually extensive because there is usually a rapid increase in peat depth to 1 m or more once 45 cm is exceeded.

2.3.3 Distribution

The development of ironpan soils is favoured by permeable sandy or loamy materials, high rainfall and relatively high altitude, northerly aspect, and by a non-woodland vegetation.

Ironpan soils are not restricted to quartzose materials as are podzols, but cover almost the whole range of rock types. They are particularly well represented on the Moine and Dalradian metamorphic rocks of the Highlands, the Ordovician and Silurian greywackes of the Southern Uplands, the Ordovician and Silurian slates of the Lake District and Wales, and the Jurassic sandstones of the North York Moors. Solifluction materials and tills are the main type of drift carrying ironpan soils, with residual material sometimes being important on hilltops. Ironpan soils are more often found on tills than are brown earths or podzols. Glacio-fluvial materials rarely occur at suitable altitudes for ironpan development. As has already been mentioned, ironpan soils characteristically grade into either brown earths or podzols at lower altitudes. There seems little doubt, from following these transitions on the ground, that they represent a developmental trend. Muir (1934) suggested two possible mechanisms for the formation of an ironpan in podzols. Briefly these may be described as (a) surface sealing by spongy humus followed by subsurface anaerobism and (superficial) gleying; (b) podzolization causing sealing of the upper surface of the B horizon followed by gleying in the overlying soil. These theories do not appear to have been modified to any great extent, or joined by others, during the last 34 years. Both mechanisms seem to be applicable to different situations although the present author feels that the second is the more widely represented. The first mechanism is closer to that which appears to occur in the development of ironpan soils from brown earths. Pyatt *et al.* (1969) have described the transition from a brown earth to an ironpan soil in Wales, a transformation which seems likely to be a trend in time as well as space. This is not to say that soils in the transitional position are necessarily moving in one or other direction of development at the present time; they may in fact be in equilibrium with their local environment. Since, however, it is known that ironpan soils are favoured by increasing altitude and by northerly aspects (that is, by cooler and more humid conditions) relative to the sites on which neighbouring brown earths or podzols occur, it is tempting to suppose that the widespread development of ironpans is correlated with the deterioration of climate of the last 2500 years. Ironpan soils are mainly found above 300 m when developed from brown earths, and above 230 m when developed from podzols. On northern slopes they extend to lower altitudes. Their maximum development seems to be at about 450 m, above which the pan becomes weaker and the soils grade into montane soils where frost is an important factor. Slopes are usually gentle or moderate, but may be steep on northern aspects; they are convex or straight rather than concave.

Ironpan soils do not appear to occur under natural woodland conditions (Steven and Carlisle 1961). The usual vegetation is a moorland or upland heath type, often with heather (*Calluna*) dominant, but mat grass (*Nardus*), blue moor grass (*Molinia*) or deer grass (*Trichophorum*) are more abundant in some localities. Obviously one would suspect that forest and ironpan soils would not suit each other, but whether there are direct causal relationships between vegetation type and soil in this context is very debatable. Dimbleby (1962) has correlated the development of ironpan soils from freely drained soils on the Yorkshire Moors with deforestation and/or the climatic deterioration, but states that while birch is naturally capable of reversing the trend pine is not. One must hope that with the encouragement of the forester pines and other conifers will be as successful as birch.

2.3.4 Forestry Properties

The peaty accumulation and the horizons above the ironpan are waterlogged and anaerobic for much of the year and present very unfavourable rooting conditions for most tree species. The more permeable conditions beneath the pan suggest that the soil may be improved through cultivation which mixes the Oh and Eg horizons and thoroughly disrupts the pan. There is plenty of evidence from cultivation experiments and field practice that deep cultivation leads to considerable improvements in survival, and in early growth and depth of rooting of trees on ironpan soils, and furthermore that more complete cultivation of the site may well be worthwhile (Taylor 1967). Although quantitative data on the effects of cultivation on the soil itself are few, the gross morphological changes, sometimes representing the re-creation of a brown earth profile, are obvious. Ironpan soils are usually responsive to phosphate applications, and potash may also be limiting on some parent materials, especially where the peat is relatively deep. Heather (*Calluna*) tends to reinvade vigorously after deep cultivation. The use of broadcast applications of phosphate to favour grasses rather than heaths may be profitable.

2.4 SURFACE-WATER GLEYS (Figs. 6 and 7, Plates 7, 8 and 9)

These are soils which suffer from periodic waterlogging due to the presence of a slowly permeable C horizon. Synonyms include pseudogleys and staugleys. Two main sub-groups are recognized.

2.4(a) GLEYS ON CLAYEY MATERIALS (Fig. 6, Plates 7 and 8)

2.4.1(a) Definition

In these soils vertical drainage is impeded by the fine-textured, dense and structureless C horizon. Below an Ag horizon of mixed mineral and humus material, an Eg horizon may occur in which gleying and removal of iron oxides in lateral seepage produce a dominantly drab greyish colour with a little ochreous mottling. The texture of these horizons is usually either coarse-loamy or fine-loamy. The underlying Bg horizon is typically clayey, prismatic in structure (has well defined vertical fissures), and strongly mottled with very pale grey and ochreous colours. The C horizon is structureless or somewhat platy—it is less strongly mottled and partially retains the natural (ungleyed) colour of the original material. It is also noticeably less wet than the overlying horizons in a freshly dug exposure (except during the summer when the whole profile may have no free water present). A non-peaty type of profile as described is usually referred to as a surface-water gley. A peaty accumulation may occur, and thicknesses up to 45 cm are allowed in the definition of a peaty gley (short for peaty surface-water gley). The peat is blackish in colour and of amorphous* structure. The Eg horizon is prominent in the peaty gley, the Ag less so. The soils of this sub-group are moderately or strongly acid near the surface but the pH rises with depth and may be near neutral (pH 7) in the C horizon.

2.4.2(b) Intergrading Situations

Intergrades with brown earths (brown surface-water gleys) and podzols (podzolic gleys) are extensive in some eastern areas. These types appear to have slightly better internal drainage than average for the group and have better expressed structure in the Bg horizon (more fissures, smaller blocky peds). The A horizon of the brown gley is only slightly gleyed and is grey-brown coloured. The podzolic gley has a sandy E horizon and a humus-enriched B horizon with little sign of gleying, followed by a mottled clayey Bg horizon in which the surfaces of the structural units are coated with blackish humus.

2.4(b) GLEYS ON INDURATED MATERIAL (Fig. 7, Plate 9)

(The term fragogleys has been proposed for this sub-group but it is not entirely satisfactory

as the *fragipan* of American soils does not appear to be wholly equivalent to the *indurated layer* of British soils.)

2.4.1(b) Definition

These are gley soils in which the impeded drainage is due to an almost impermeable indurated layer. An organo-mineral Ag horizon overlies an Eg horizon in which gleying is usually strongly expressed in terms of a pale olive-grey colour. A strongly mottled Bg horizon is usually lacking, the Eg horizon being directly underlain by the indurated C horizon. This retains a good deal of the natural colour of the parent drift, but gleying occurs as ochreous mottles and as large olive-grey wedges and patches. Textures are usually coarse-loamy throughout. Peaty indurated gleys with up to 45 cm of peat are also included within the sub-group. Gleys on indurated material are strongly acid near the surface, and the pH rises only slowly with depth.

2.4.2(b) Intergrading Situations

Intergrades with brown earths and podzols appear to be fairly unimportant, but the soil described in the ironpan soils group with deep-lying ironpan resting directly on the indurated material may represent a rather important intergrade type.

2.4.3(a) and (b) Distribution

Surface-water gleys are favoured by impeded parent materials, high rainfall, and by very gentle slopes especially when concave.

Sub-group (a) is very extensive on the outcrops of Carboniferous sediments where clayey tills are dominant and where topographic and climatic factors are also generally favourable. Similar materials give rise to large areas of these soils on the Ordovician and Silurian greywackes of the Southern Uplands of Scotland, and in Wales on the slates of the same systems. Clayey textured residual and solifluction materials are provided by shaly beds of Jurassic age on the North York Moors and by Carboniferous Culm slates in Southwest England.

Indurated tills derived from Old Red Sandstone sediments give rise to large areas of subgroup (b) soils in the Moray Firth hinterland. The extent of surface-water gleys on the Moine and Dalradian rocks of the Highlands is not well known, although it appears that they usually conform to the indurated subgroup. Peaty indurated gleys are known to be extensive on the relatively subdued landscape of central Sutherland.

The extent and true nature of surface-water gleys of both sub-groups in heathland areas of eastern Britain has only recently been fully appreciated as a result of forest soil survey.

2.4.4(a) and (b) Forestry Properties

The presence of a seasonal perched water-table in the upper part of the profile leads to the development of anaerobic conditions. Roots are only able to grow reasonably healthily in the A horizon (or in the O horizon of peaty gleys), because roots which penetrate to deeper levels in summer when the soil is free of waterlogging are killed back during the following winter. Tree species show a wide range of tolerance of such conditions, but of the species grown in upland forests only alders can be said to be "at home" on clayey soils and capable of rooting to depths of 1 m or more. Spruces and Lodgepole pine produce reasonable yields, especially in flushed sites where the excess water is kept moving, but in crop conditions do not develop root systems giving adequate stability to maturity. Drainage must be deep enough to allow water to move out of the fissures in the subsoil; these usually extend to a depth of about 1m. Drain spacing may be varied with the lateral conductivity of the soil, but in present practice only ground slope is taken into account (Henman 1963). There is a popular misconception that these soils can be "over-drained" to the disadvantage of the crop in drought periods. In fact

only *excess* water can be removed from surface-water gleys by draining, and it is by increasing the rooted volume of soil that a greater storage capacity is made available to the crop for use during the summer, at which time the soil is free of excess water regardless of whether it is drained or not. The misconception may have arisen partly because of confusion of these soils with ground-water gleys.

The gleys on indurated material are distinguished from the clayey soils because deep drainage alone will probably not enable roots to penetrate the indurated layer. Some form of deep cultivation in addition to normal draining appears to be necessary, but experimentation into this problem is only at a very early stage. There appears to be a rather wide range of drainage status within this sub-group, resulting in varied crop performance.

Soils of both sub-groups are usually responsive to phosphate especially when peat is present, and potash may be beneficial in some cases. The special problems presented by surface-water gleys of both sub-groups when carrying *Calluna*-dominant vegetation have recently assumed prominence. Such sites are much more extensive in the so-called upland heaths (Zehetmayr 1960) than was thought formerly and have received little attention from research workers. Scots pine, the traditional choice of species for most of these sites, is intolerant of the poor drainage. Lodgepole pine appears to be much more tolerant of the conditions and is nowadays more often used, although its yield potential is also rather low.

There is reason to believe that with the help of recently developed herbicides and/or the use of *broadcast* dressings of phosphate fertilizer at a rate somewhat higher than usual for spot application, grass species can be favoured to the extent that *Calluna* need no longer be a serious problem. This may enable the potentially more productive species such as Sitka spruce and Western hemlock to be more widely used on these soils.

2.5 GROUND-WATER GLEYS (Fig. 8)

2.5.1 Definition

These soils are influenced by a true ground-water table supported by an impervious layer below the C horizon of the profile. In upland areas the impervious layer is often bedrock, the soil being formed in a relatively permeable superficial deposit, and while in some instances the deposit may be deep so that the bedrock does not feature in the profile as such, examples are known where the depth of soil over bedrock is less than 1 m. The *peaty gley, shallow phase* of north and mid Wales conforms to the latter category (Pyatt *et al.* 1969). Ground-water gleys also occur where sandy sediments overlie clayey sediments in undulating topography, but these are more important in lowland than in upland areas. Certain strongly flushed soils, the material of which is evidently permeable in itself but which have a gleyed profile, are included in the ground-water gley group, as also are most soils on recent alluvium.

The typical profile consists of an organo-mineral Ag horizon overlying a Bg horizon which is grey with ochreous mottling. The Cg horizon is dominantly grey or even bluish and is permanently waterlogged. Textures are usually coarse-loamy or sandy. The reaction is moderately or strongly acid near the surface, but is usually much less so at depth and may be alkaline in the Cg horizon. Shallow soils over bedrock tend to be strongly acid throughout. Soils which are strongly flushed may be only slightly acid at the surface, and where the water comes from limestone rocks the soil may be alkaline throughout.

2.5.2 Intergrading Situations

Ground-water gleys are not very extensive in upland Britain and no significant intergrading situations have been encountered in forest soil mapping.

2.5.3 Distribution

The rarity of a true ground water-table in up-

land Britain is in marked contrast with the familiar textbook picture of the all-pervading water table which has only to be dug for to be discovered in all parts of the landscape, albeit at varying depths. In the uplands slopes are often too steep and the upper layers of the bedrock too fractured to permit the formation of a water table in the normal sense of the term. In many other parts where the topography is favourable, the bedrock is too permeable or (more often) the soil itself contains an impervious layer. Ground-water tables are provided locally by impermeable bedrock overlain by relatively shallow soil, as in the peaty gley, shallow phase of Wales. Similar soils might also be expected to occur on the massive metamorphic rocks of the Scottish Highlands. Alluvial soils of the valley bottoms are usually affected by a genuine, though localized, water table.

2.5.4 Forestry Properties

The problems encountered in draining ground-water gleys differ from those found with surface-water gleys, and are mainly due to the presence of the permanent water table. Rapid fluctuations of the level of the water table may be caused by each period of heavy rain, and these are usually superimposed on a slow, seasonal fluctuation, the magnitude of each depending on local soil and topographic conditions. In general, when the water table is deep-lying its fluctuations are relatively small, and vice versa. The depth to which drains should be formed depends on the minimum depth of rooting required, bearing in mind that the water table rises nearer the surface with increasing distance from the drain. The steepness of the rise depends on the permeability of the soil (steeper in less permeable soil), and hence the drain spacing should be chosen to give an acceptable depth of rooting midway between drains. The water table will usually fall below drain depth during dry summer periods and may then be out of reach of the root system. This may be a problem in agriculture and is probably the origin of the idea of over-draining, but tree crops should not suffer from drought if the drains have provided a good depth of rootable soil. Soils with sandy or coarse-loamy textures are usually non-cohesive when saturated, and when drains are initially formed the material may flow and rapidly infill the drain (the familiar "flowing sand" condition encountered on the beach). This is unavoidable to some extent, but can be reduced by commencing drainage operations at the outlet end of the catchment area. Under such circumstances the desired lowering of the water table cannot be achieved in one operation; repeated drain cleaning and deepening is necessary as the water table is gradually lowered.

Many ground-water gleys are enriched by strong flushing and have high nutrient levels. Some of the soils overlying shallow bedrock appear to lose more nutrients than they gain and are impoverished. These variations in fertility are evident in the ground vegetation. Alluvial soils are frequently among the most productive in the forest for all but frost-tender species.

2.6 DEEP PEATS (Plate 10)

2.6.1 Definition

These are defined as peats deeper than 45 cm. The author's experience of deep peats in the western and northern parts of the Scottish Highlands is limited, and the assistance of Mr D. B. Paterson, present Site Survey Officer, with the preparation of this outline provisional classification is gratefully acknowledged.

(a) *Fen peat* (eutrophic* peat) accumulates in sites affected by flushing water emanating from calcareous rocks. The peat is black, amorphous in structure and has a pH above 6·0. Calcicolous plants are usually present.

(b) *Flushed basin peat* (mesotrophic* peat) occurs in basin or concave sloping sites where there is strong flushing from non-calcareous rocks. Mineral material is often interlayered

with the peat, which is black and amorphous. The pH is 4·0 to 6·0. Peat depth rarely exceeds 1 m. Bare ground vegetation contains tall rush (*Juncus*) species, either *Juncus articulatus*, *J. acutiflorus* or *J. effusus*. *Molinia* may be abundant but is not diagnostic in the absence of *Juncus*.

(c) *Molinia bog* (oligotrophic* flushed bog) usually occurs on concave sloping sites rather than in definite basins, where the flushing is of a fairly low intensity. The peat is amorphous or pseudofibrous*, has a pH between 3·6 and 4·8, and is less than 3 m in depth. The characteristic species of bare ground is *Molinia*; the tall *Juncus* species are infrequent. *Calluna* and *Sphagnum* mosses may be quite frequent especially in transitions to type (d).

(d) *Non-flushed Sphagnum bog* (non-flushed oligotrophic bog) develops from the previous types when the increased accumulation of peat raises the bog surface effectively above the influence of the flushing. The type includes the so-called *raised bogs* which have developed a convex surface, but also many which still have a flat or slightly dished surface. The peat is mainly pseudofibrous, with a more fibrous* upper layer of variable thickness. The pH is 3·4 to 4·5, and peat depth is usually in the range 3 to 5 m. Bare ground vegetation is somewhat variable due to the effects of moor-burning and grazing, but typically includes abundant *Sphagnum*, the cotton grasses *Eriophorum vaginatum* and *E. angustifolium*, *Calluna* and *Trichophorum*.

(e) *Hill peat or Non-flushed slope bog* (non-flushed oligotrophic bog of variable depth on convexities). This type occurs on flattish or convex hilltops, or slopes which may exceed 5°. Flushing has therefore played a very minor role in its development. The peat is dense and relatively firm, fibrous or pseudofibrous in structure and frequently overlies an ironpan soil profile. The pH is 3·4 to 4·5. Peat depth is variable, ranging from 45 cm to 4 m, but is usually less than 2 m. The vegetation is often dominated by *Calluna*, though *Trichophorum* tends to take over if moor-burning is intensive. In regions south of the Highlands, especially in Wales, *Vaccinium myrtillus* may tend to replace *Calluna* as the dominant vascular plant. *Sphagnum* is usually less abundant than on type (d). *Molinia* is absent.

2.6.2 Intergrading Situations

Intergrades with other groups occur at the lower limit of peat depth. The subdivision of the deep peats group is mainly concerned with nutritional status, but the choice of the lower limit of peat depth for the group is a compromise between several considerations. It is intended to separate *deep* peats in which trees will usually root only in organic material, from peaty-topped mineral soils in which most trees will reach mineral material, with important mechanical and nutritional consequences. Young trees may show nutritional deficiency symptoms on peats shallower than 45 cm, but it is believed that the long-term nutritional differences between deep and shallow peats are best separated at about 45 cm. The use of a 45 cm limit reduces the justification for recognising an additional group or subgroup of peats of intermediate depth.

Intergrades between the types of deep peat are indicated by vegetation of intermediate species composition. In this group of soils especially there is a marked continuity of variation, and in our present inadequate knowledge there is still a considerable subjective element in the delimitation of categories.

2.6.3 Distribution

Deep peat accumulations are favoured by impeded substrata, flat or gently sloping topography especially when concave, and by high precipitation effectiveness.

The most extensive areas of deep peat are found in Caithness and Sutherland where impermeable tills lie on very subdued topography, in spite of a climate which is little different from other regions of eastern Britain where deep peat is quite rare. The

effect of climate is better seen in regions of relatively uniform parent material and topography such as Wales where hill peat is restricted to areas with precipitation more than 1400 mm per annum. Fen peat is very rare in upland Britain. Mesotrophic peat and oligotrophic flushed peat are widely distributed but always occur as small areas. The oligotrophic non-flushed peats are much more extensive in those regions presenting suitable conditions. Deep peats are *unimportant* in forest areas in several major regions, notably Southwest England, North York Moors, Wales below 360 m altitude, the Lake District and the Moray Firth hinterland.

2.6.4 Forestry Properties

Deep peats require intensive drainage for successful forestry, probably more so for crop stability requirements than for improved growth. Deep peats react to drainage operations more like non-cohesive ground-water gleys than surface-water gleys. Flow takes place to produce a rapid reduction in drain depth and width, and repeated deepening may be necessary before the water table is lowered to the desired depth and the peat is stabilised. Some collapse (shrinkage) of the peat occurs following the loss of water which also tends to reduce the effective drain depth. Lateral conductivity of peats is lower than that of most ground-water gleys, but is higher in fibrous than in amorphous or pseudofibrous peats. Drain spacings are usually closer than in mineral soils, but in small bogs use can be made of efficient cut-off (perimeter) drains to intercept the flush water.

The nutritional status of the peat types (in terms of the availability of nitrogen, phosphorus and potassium) is considered to decrease generally through the sequence a, b, c, e, d. On types a, b and c crops of spruce may sometimes be grown satisfactorily without fertilizer, but it is generally considered worthwhile to apply a phosphate fertilizer at planting, and potash is usually necessary to correct deficiency symptoms at a later stage on types b and c. It is not yet certain whether additional phosphate will be required on type c. On peats of type e Sitka spruce is often planted, especially in southern regions, although Lodgepole pine is more usual in the north and east. Phosphate at planting is essential, and potash is required at a very early stage and may in fact be worthwhile at planting, especially for spruce. Long term nitrogen availability on this type is uncertain, but it seems likely that repeated NPK applications will be necessary to maintain vigorous growth, especially of spruce. Type d peats are very low in N, P and K. The indications are that for Lodgepole pine PK should be applied at planting and at intervals during the rotation, and that the nutrition of spruce can only be maintained with repeated NPK applications.

2.7 SOILS ON CALCAREOUS ROCKS
(Fig. 9, Plate 11)

2.7.1 Definition

Included within this group are rendzinas, brown calcimorphic soils and argillic brown earths (*sols lessivés*). Rendzinas usually have a profile consisting of an A horizon overlying an R horizon, and are shallow to bedrock. They also occur on calcareous drift in which case the A horizon overlies an unconsolidated C horizon, but these are probably very rare in upland Britain. The A horizon of rendzinas may be slightly acid in reaction but the R horizon is strongly calcareous. Brown calcimorphic soils have an A,B,R or A,B,C profile and the A and B horizons resemble those of a normal brown earth and are sometimes non-calcareous. Depth to the calcareous R or C horizon is greater than in the rendzina but usually less than 45 cm. Argillic brown earths are usually more than 45 cm and may be more than 1 m in depth to rock. The profile has A,E,Bt,C or A,E,Bt,R horizons. Clay particles are washed down the profile from the A and E horizons to form a clay-

enriched Bt horizon resting sharply on the calcareous material. The A horizon is dark brown, the E is light yellowish brown, and the Bt horizon is a somewhat reddish brown. Textures of the A and E horizons are loamy, the Bt horizon is fine-loamy or clayey. A, E and Bt horizons are moderately to strongly acid. The drainage class of all three types is free, and the soils are friable, well structured and freely rootable to the bed rock.

2.7.2 Intergrading Situations
None of these types is extensive in upland forests, and no significant intergrades between them and the soils of other groups have been encountered. It is conventional to include argillic brown earths which are less than 45 cm to rock with the brown calcimorphic soils in soil survey, thereby attempting to separate soils giving chlorosis problems from those which do not produce serious symptoms.

2.7.3 Distribution
Small outcrops of calcareous rocks occur in Scotland in the Dalradian assemblage and in the Cambrian of the far northwest. In England and Wales the Carboniferous limestone occasionally intrudes into forest areas, notably in the eastern and southern Pennines and in northeast and south Wales. The Jurassic limestones of the North York Moors give rise to the most important areas of these soils in upland Britain. True rendzinas are rare as the soils are mainly formed in a drift derived from the overlying stratum, but brown calcimorphic soils and deeper argillic brown earths are widespread.

2.7.4 Forestry Properties
This is an arbitrary grouping of three related but diverse soils. The rendzina has very severe limitations of high pH and usually shallow depth, with liability to droughtiness. Few conifers are able to tolerate such conditions without severe chlorosis symptoms, and many die within a few years. Beech is the most tolerant major species, but even this is not at its best on rendzinas. Brown calcimorphic soils are less severely limited than rendzinas, and will usually produce satisfactory crops of Corsican pine, Western red cedar, Lawson cypress and the Serbian spruce, *Picea omorika*, but chlorosis is always present to some degree. The fungus *Fomes annosus* is also usually very prevalent under these conditions and causes progressive deaths in pines, and butt rot in many other conifers. Rendzinas and brown calcimorphic soils tend to be extremely weedy, and woody species such as hawthorn, blackthorn, dogwood and briar can be a great nuisance. Argillic brown earths are much closer in behaviour to normal brown earths than are the previous types. They combine the cardinal virtues of acidity, free drainage and friable consistence allowing healthy rooting through the A, E and Bt horizons. The presence of calcareous material beneath does not appear to be a disadvantage in these circumstances. Although somewhat limited in depth at the shallow end of the range, these soils are excellent for most conifers and many hardwood species.

2.8 OTHER SOIL TYPES
Soils which are not considered worthy of inclusion because they do not fit any of these groups and are of insufficient extent to justify special groups include *rankers* which are shallow soils with A,R profiles on hard non-calcareous rocks, and dune sands which the pedologist classes as *regosols*, that is, very young soils on unconsolidated materials.

ACTIVE LAYER – see PERMAFROST

AMORPHOUS – applied to peat or thin organic layers in which humification has proceeded to the extent that recognizable plant fragments constitute less than 1/3 of the material, the bulk consisting of highly disintegrated material of microscopic size. There may be an appreciable proportion of mineral soil particles mixed throughout or occurring in layers. These derive from erosion of neighbouring higher ground and usually indicate active flushing of the peat site. Amorphous peat is black or dark brown in colour. It shrinks markedly on drying, forming hard angular coal-like fragments. This definition, and those of fibrous and pseudofibrous peat, are based on the descriptions by Fraser (1933).

CLAY – soil particles less than 0·002 mm in size, and possessing colloidal properties. (See also TEXTURE.)

CONSISTENCE, SOIL – refers to the strength and kind of cohesion between soil particles in a structural unit, or within the soil mass if structural aggregation is not evident. Consistence varies with moisture content and is normally assessed when the soil is moist (rather than dry or wet) by squeezing a lump between the fingers. Terms used are friable, firm, very firm, etc., depending on the amount of effort required to deform the soil. Root development is restricted in very firm soils.

EUTROPHIC – having concentrations of nutrients relatively favourable for plant growth.

EVAPOTRANSPIRATION – the combined loss of water from a given area during a specified period of time, by evaporation from the soil surface and vegetation and by transpiration by plants.

FIBROUS – applied to peat or thin organic layers which are only slightly humified and contain over 2/3 of distinguishable plant structures. Most of the fragments exceed 1 mm in length and retain sufficient mechanical strength to resist disintegration or become greasy when rubbed while wet. Fibrous peat varies in colour and structure according to the conditions of accumulation. It varies from light brown to almost black, and from a tough stringy material or almost raw *Sphagnum* to soft wadding-like material with a very short fibre. Fibrous peat shrinks little when dried. It may darken appreciably when exposed to the air, especially in forms transitional to pseudofibrous peat. When squeezed, clean or slightly turbid water exudes, the bulk of the material remaining in the hand.

ICE WEDGES – see PERMAFROST.

INDURATED MATERIAL – a type of C horizon occurring in certain glacial and periglacial deposits, which is compact and of high bulk density and of firm to extremely firm consistence. It is low in organic matter, sandy or coarse-loamy in texture (rarely fine-loamy), and slightly to very stony. Sand grains are angular in shape. The silt fraction is usually prominent. Coatings of predominantly silt and fine sand material adhere firmly to the upper surfaces of stones and sometimes to structural units. The structure is massive or platy, the platiness being most marked in the upper part of the layer. The material is slowly or very slowly permeable to water and roots, except within a roughly polygonal pattern of vertical cracks which are infilled with pale greyish, gleyed soil. Colour is variable depending on the parent rocks, but is usually light greyish or yellowish brown. The upper surface of the layer is usually abrupt and appears at depths of 30 to 75 cm, most commonly at about 45 cm. The thickness of the layer varies from 30 cm to more than 1 m and the lower boundary is gradual.

Indurated material represents the relic permafrost layer formed in periglacial conditions. Soil processes may bring about certain modifications to the original features. In freely drained podzolized soils the clay fraction of the upper 30 cm of the layer is enriched with aluminium relative to the overlying horizons, and it has been suggested that aluminium oxide acts as a cement giving a brittle consistence to the material (Glentworth 1944, Romans 1962). Crampton (1965b) found translocated clay filling the interstices between the densely packed sand and silt grains of an indurated layer with an abrupt upper surface.

Indurated layers are widespread in the Highlands and Southern Uplands but are relatively uncommon elsewhere. In Wales and Southwest England indurated material is largely restricted to the deepest drifts and to soils which are poorly drained.

The term *fragipan* is sometimes used as an alternative for indurated layer. Fragipan is the name given to similar but probably not identical layers in some soils of North America. The term *induron* has recently been coined by FitzPatrick (1967) for the indurated layer of British soils, (since changed to *ison*).

MASSIVE – see STRUCTURE.

MESOTROPHIC – having nutrient concentrations intermediate between those of eutrophic and oligotrophic soils.

OLIGOTROPHIC – having very low nutrient concentrations far below the optimum for plant growth.

PED – see STRUCTURE

PERIGLACIAL – used for climatic conditions and superficial deposits formed at high latitudes and high altitudes where frost is the dominant factor in weathering and landscape evolution. There is sufficient summer thawing to produce at least partial ice-free conditions. Frost shattering of rock, solifluction, the formation of permafrost and ice wedges are features of periglacial regions. 'Fossilized' examples of these features can be seen throughout upland Britain.

PERMAFROST – In a periglacial climate the soil and rock debris is frozen solid to a considerable depth, from several metres to two or three hundred metres depending on the severity and duration of the cold. This layer, known as permafrost, consists of alternating layers of clear ice and soil or rock debris if formed in drift, but may extend down into bedrock. The uppermost ½–2 m which has a major annual freeze-thaw cycle is known as the *active layer*. The deepest active layers occur in relatively dry, sandy soils on southern aspects, and when devoid of insulating vegetation. It is the active layer which takes part in solifluction (mass flow downslope). *Ice wedges* (frost wedges) are vertical veins of ice occurring in permafrost, and are formed by the annual freezing of meltwaters draining into contraction cracks in the ground. They grow by annual increments and thus their size is an indication of their age. Their depth of penetration indicates the minimum permafrost depth. When the permafrost eventually thaws, the wedges become infilled with material from above and fossilized.

PSEUDOFIBROUS – applied to peat which has a fibrous appearance but in which the fibres have undergone partial decomposition so that their strength and tenacity are lost. The material has a gelatinous nature, and when squeezed in the hand the bulk of the peat exudes between the fingers and little water is released although it is evidently saturated. When pseudofibrous peat is exposed to the air, changes take place whereby the fibres regain their strength and the peat becomes fibrous and rigid yet very light in weight. The colour is yellow brown or orange brown when freshly exposed, but rapidly darkens to almost black.

SAND – soil particles between 2·0 and 0·06 mm in size; sometimes this fraction is divided into coarse sand 2·0–0·6 mm, medium sand 0·6–0·2 mm, and fine sand 0·2–0·05 mm. (See also TEXTURE.)

SILT – soil particles between 0·06 and 0·002 mm in size. (See also TEXTURE.)

STONES (SHAPE OF) – The shape of stones is a clue to the mode of formation of the drift containing them. Well *rounded* stones indicate prolonged water action. At the other extreme, sharply *angular* fragments indicate frost action in formation and minimal transportation. Intermediate shapes are *subangular* (blunt edges and rounded corners) and *subrounded* (partially rounded), and may indicate transportation largely by ice.

STRUCTURE, SOIL – refers to the aggregation of the soil particles (sand, silt and clay) into compound units or *peds*, which are separated from adjoining aggregates by surfaces of weakness. Soils with no evident aggregation are described as having either *single-grain* structure, or *massive* structure if cohesive. (Massive is also applied to bedrock which is not fragmented.) Structural units are described according to their shape as *crumb* (rounded), *angular blocky* or *subangular blocky* (like stones of those shapes), *prismatic* (vertically elongated) or *platy* (flattened).

TEXTURE, SOIL – refers to the relative proportions of the size fractions (sand, silt and clay) present in the soil sample. Several textural classifications are in use for different purposes, but the most widely used in soil survey is that of the United States Department of Agriculture (USDA 1951). The textural classes are described by terms such as sand, loamy-sand, sandy-loam, loam, silt-loam, clay, etc., and may be represented on a triangular diagram. Recently a simplification of the system has been proposed (USDA 1967) which reduces the number of classes from twelve to seven, and which appears to be adequate for forest soil classification. The two systems are compared on the diagram below. The definitions of the new classes are as follows (S = sand, Z = silt, C = clay):

sandy textures	S > 70%	Z < 30%	C < 15%
coarse-loamy textures	S > 15%	Z < 85%	C < 18%
fine-loamy textures	S > 15%	Z < 68%	C 18–35%
coarse-silty textures	S < 15%	Z > 68%	C < 18%
fine-silty textures	S < 15%	Z 50–83%	C 18–35%
clayey textures (fine)	S < 65%	Z < 65%	C 36–60%
clayey textures (very fine)	S < 40%	Z < 40%	C > 60%

In upland Britain the clayey (very fine) texture class is so uncommon that it can be amalgamated with the clayey (fine) class, thereby reducing the number of classes to six.

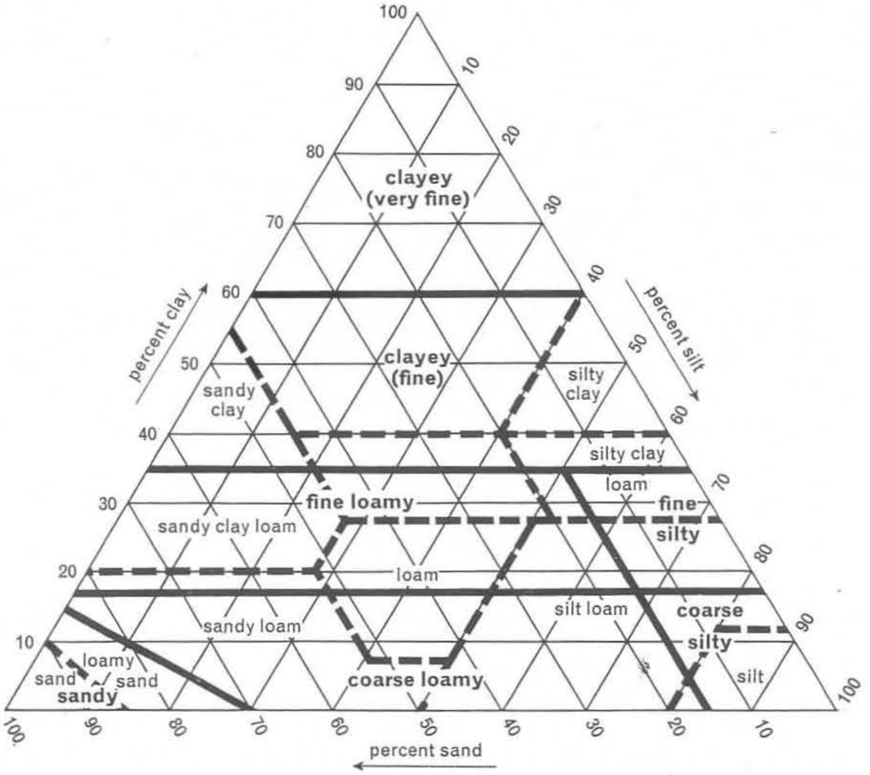

Fig. 10. Diagram of Texture Classes. Broken lines:—present system of 12 classes. Solid lines:—proposed system of 7 classes. (The boundary line between loamy sand and sandy loam is common to both systems.

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